No 495 1958 NOV.—DEC.

GEOLOGISKA FÖRENINGENS

I STOCKHOLM

FÖRHANDLINGAR

UTGIVARE

PER H. LUNDEGÅRDH

BAND 80 HÄFTE 4

Edited by the Geological Society of Stockholm

Stockholm 50

Subscription by Nordiska Bokhandeln, Stockholm 1

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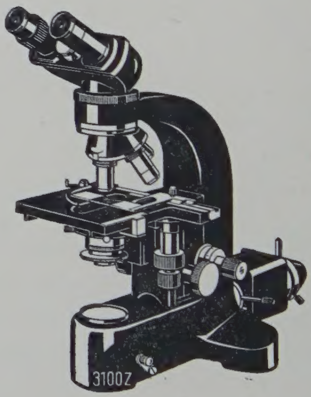

GEOLOGISKA FÖRENINGENS
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Toward a Further Hypothesis on the Scandinavian Caledonides

By

MAURITS LINDSTRÖM

Abstract. A synopsis is prepared of the strike of 1474 lineations and 796 sub-vertical s-surfaces indicated on published maps of areas in the Scandinavian Caledonides. The material seems to support the hypothesis that parts with different strike were largely deformed during different phases, and that a given phase of deformation gave origin to about the same strike wheresoever it had effects. It is suggested that there were at least three main deformation phases, first one with transport toward about ESE, then one with transport toward about SSE, and finally one with transport toward S (and E). The first phase is taken to have affected the whole of the mountain chain. Its traces are best preserved and dominate in the central parts. The second phase had its chief effects in the north and in the southwest, where its strike directions dominate in the maps. The last phase dominates locally in different parts of the mountain chain.

The Caledonides of Scandinavia arose by shortening of the Earth's crust in NW—SE, with big overthrusts toward SE as a result. Little is known about this process. Most hypotheses that exist take for granted either or both of the assumptions that there was one single main phase of deformation, whether short or prolonged, and that there was a single direction of main transport. (A couple of noteworthy exceptions are dealt with later on in this text.) These assumptions are specific. A reduced, generalized assumption for the case is that there may have been any number of deformation phases and any number of transport directions, the directions at right angles, and parallel, to the regional strikes being the most probable ones. It will then remain to be proved, how many phases and directions that can be found.

Clearly, the condition for a differentiation of transport phases in a certain area is that we find distinct populations of deformation structures that differ constantly in some respect, e.g., as regards direction of strike, as regards characteristics of the deformation planes, or as regards proved geologic age of the rocks affected.

I have collected a great number of tectonic data in two parts of the Caledonides of NW Europe. In both these parts, there are different, quite distinc populations of linear structures.

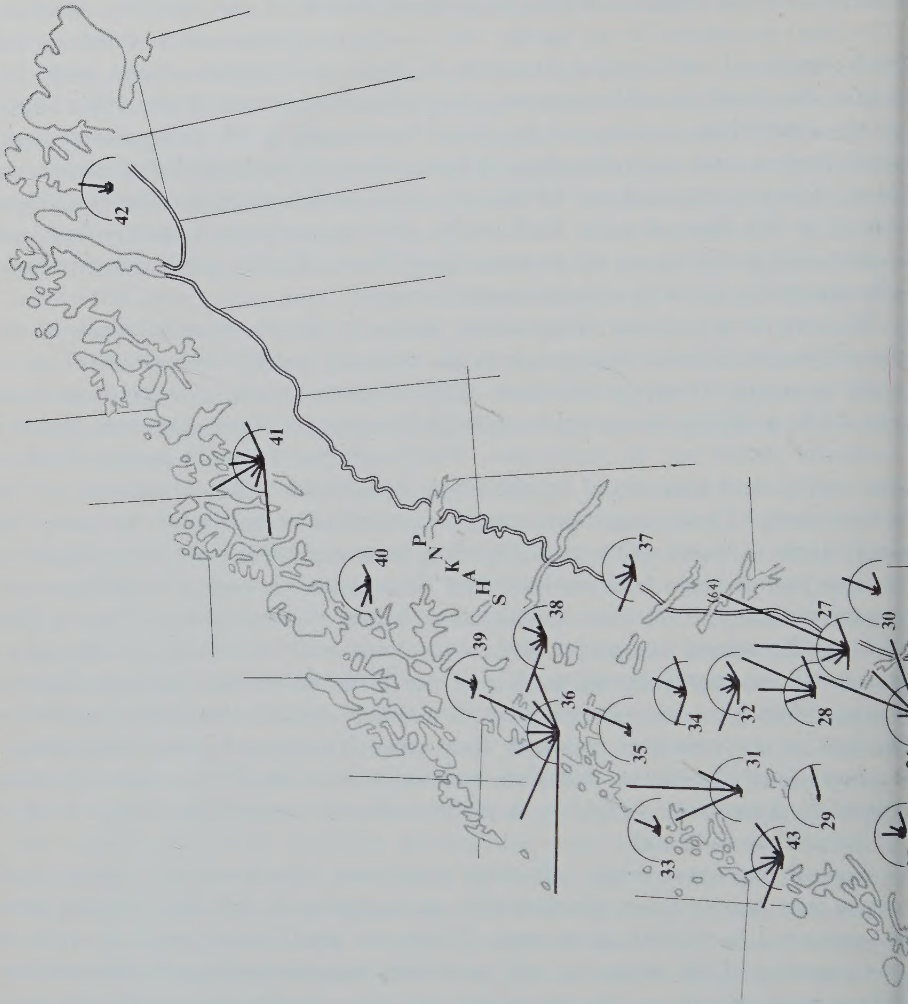
In six small areas (P, N, K, A, H, S, of the map, fig. 1. See LINDSTRÖM 1957 1958 a & b) in the Swedish Caledonides, north of the Arctic Circle, the orienta tion of altogether 3370 "lineations" (defined in op. cit.) and 4550 s-surface has been determined as exactly as possible, with notations as to a few charac teristics, i.a. relative age of lineations found to intersect one another on th same s-surface. It has been possible to conclude from the material that ther were at least three phases of deformation in these areas. The phases can b subdivided into stages, with rather different degrees of certainty. Each stag is characterized by a certain direction of transport that is surprisingly constan from area to area. During the first discernible phase, the Palnoluokta phase transport went in directions about ESE, then, during the Trappsteget phase there was transport toward about SSE, after which the Raijkijokka phase cam with transport toward E and (or?) S.

In the tightly folded Ordovician and Silurian greywackes and shales alon the coast of the Rhinns of Galloway, in the extreme southwest of Scotland, th orientation of 1600 bedding-planes and 2090 joints has been recorded (LIND STRÖM 1958 c). Two populations of fold axes are very distinct and coincid fairly well in orientation with two populations of joint normals. From th evidence collected, it is clear that there was first transport toward about N 32 W, then toward about S 15° E. These directions are quite constant all throug the area investigated. Both in this case and the Swedish ones, the different axia trends partly occur together, in the same localities, and partly dominate dif ferent sections and tectonic units, so that the fabric of an area of some size i almost entirely dominated by one set of linear structures. Two adjacent region that are dominated by different deformation axes will of course also diffe i.a., in main regional strike, so that a deflection will appear on the geologic and probably also the topographic map. The deflection may be even and smoot rather than abrupt, as there is often an intermediate zone where neither o the two tectonic axes is entirely dominant (but where, on analysis, each of th two axes can nevertheless be shown to be represented by a distinct populatio of linear elements).

As there is clear evidence of different deformation phases in the only tw parts of the Caledonides, with which I am to some extent familiar, it is natura for me to believe that similar conditions will be found in other parts of th mountain chain as well. The constancy in axial trends in the 85 km lon section made up by the areas in northern Sweden has led me to the belie that the direction of transport of a given deformation phase may have bee the same over even greater distances. The movement of a tectonic unit wit an areal extent of hundreds of km^2 is hardly a local incident. However th forces are applied that cause the movement, they must arise on transport o masses in even greater contexts. The movement direction and its traces in th tectonic unit will reflect the direction of the forces, and the course of the mor large-scale events will determine the whole. As a whole, the vast tectonic shee cannot be rigid. There will thus be local deviations of the transport direction. The local deviations do not matter very much, for if they are summed up, the main transport will appear. However, if there are separate phases with different directions of main transport, each of which appears in the whole extent of the sheet, these events must be caused by changes in the fundamental large-scale process, and such changes will have effects of some kind, far outside the area of our tectonic sheet. Of course, it is possible that the distinct phases found in this sheet are the local effects of a source process that is long and continuous, but even so, the changes found from phase to phase must indicate changes going on in the fundamental process.

If there were separate deformation phases in the whole or in much of the Scandinavian Caledonides just as in the areas in north Sweden, and if, as in these areas, the transport direction changed in the course of the process, there should be a very great variation of strike directions of linear elements, and this variation should not be continuous, but should have distinct modes. Further, the variation of axes found for the whole should also be found in many of the minor parts. These conditions can be checked to some extent, by using the indications of axial strike given in some texts and on a good many maps of various minor areas with undoubtedly Caledonian tectonites. The linear elements collected from these publications belong to two groups. To the first belong "lineations", or major and minor folds and "stretching". These structures are frequently homologous, and are often shown by the same sign on maps. They have in common that they should tend to be either parallel or normal to the transport in which they arose. The second group comprises s-surfaces (bedding-planes, foliation, schistosity) that dip 70° or more. As mentioned by LANDMARK (1951) such planes with sub-vertical dips should tend to be parallel to fold axes.

Several important errors adhere to these data. There are the unintentional errors that must arise in my recording of the strikes of the map symbols, however much I have tried to be exact. There are equally unintentional errors in the drawing of the maps, as well as in the mapping geologist's observations. These errors should not be systematic and can probably be neglected. A good many of the lineations recorded may be generalizations for an outcrop or a series of outcrops. Such estimates may have been influenced in several ways causing systematic errors. There is a very frequent tendency to group a strike direction under the nearest direction ending with 0, or 5. For instance, folds striking N 76° E and N 83° E may be more likely than not, to be recorded as striking N 80° E. Or, e.g., folds striking in any direction from N 55° W to N 80° W are noted as striking "WNW", after which they are most likely to be rendered as striking N 67° W on the map. Most authors will agree that their maps were not drawn in order to serve as reference material for exact observations on axial strikes. If it will be justified to draw certain conclusions from the material, the very nature of the material, as well as its relative scarcity, makes it necessary to regard these conclusions with some skepticism, i.e., as hypothetical.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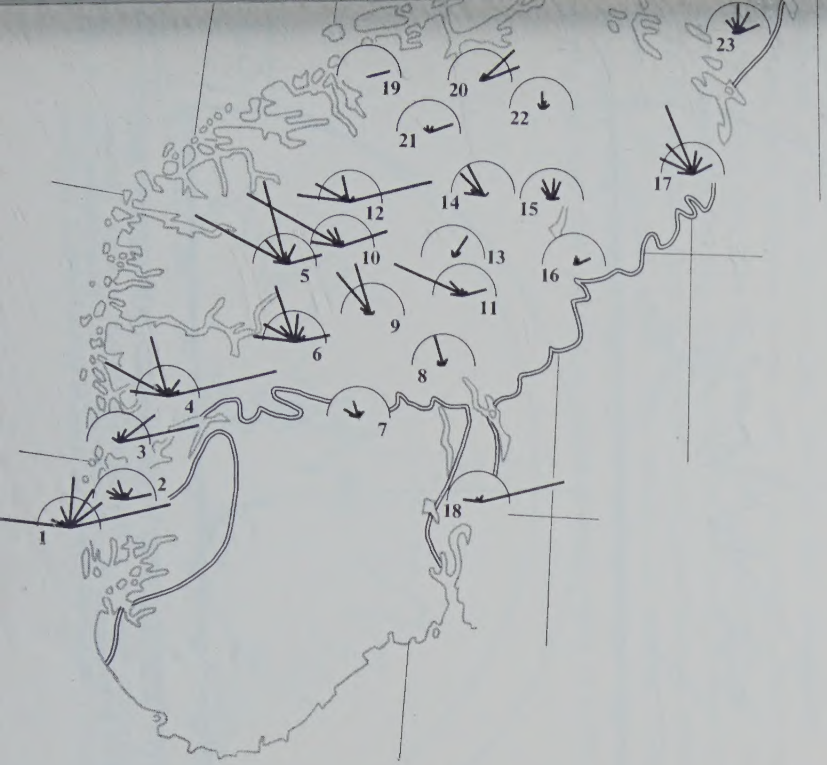

Fig. 1. The Scandinavian Caledonides. Axial strikes according to published information, divided into eight orientation classes. A diagram inserted for each area shows the frequency of the orientation classes. The semi-circles of the diagrams indicate the frequency 10. The semi-circles are oriented in W—E. Letters P, N, K, A, H, S indicate the position of six areas investigated by the author. The approximate SE border of Caledonian tectonites is indicated by a double line.

The map, fig. 1, shows roughly where the main areas are situated, for which it was possible to obtain axial strikes from publications. Below, the publications are listed under the numerals used for the areas on the map.

1. Reusch 1888. — **2**. Sørbye 1949. — **3**. Foslie 1955 (lineations and fold axes only). — **4**. Kvale 1948 (lineation and fold axis maxima ≧ 5 %, from the diagrams pls. 14—21). — **5**. Landmark 1949. — **6**. Strand 1950. — **7**. Strand 1954. — **8**. Strand 1939. — **9**. Strand 1945, D23, p. 31. — **10**. Strand 1951, p. 28. — **11**. Bjørlykke 1905, pp. 1—158. — **12**. Bjørlykke 1905, pp. 220—399. — **13**. Marlow 1936. — **14**. Holmsen 1948. — **15**. Holmsen 1943, p. 49. — **16**. Oftedahl & Holmsen 1950. — **17**. Stålhös 1956, pp. 303, 318, 325, pl. 1; Strömberg 1955. — **18**. Brøgger 1882, Profil von Hövikskjär; Kiær 1908, pls. 22, 23, p. 415, maps 1, 3; Skjeseth 1952, p. 141; Størmer 1933, p. 117. — **19**. Hernes 1956, pp. 30, 31. — **20**. Vogt 1945. — **21**. Holtedahl 1938, p. 32; Rosenqvist 1941, p. 27. — **22**. Vogt 1940, p. 173. — **23**. Asklund 1935,

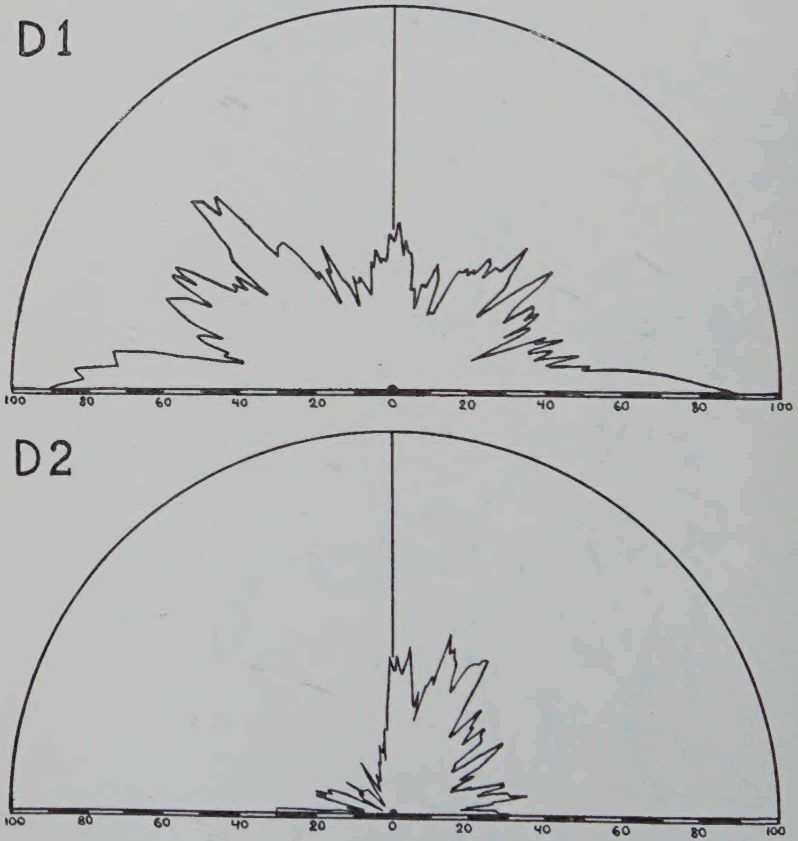

Fig. 2. — D 1. Rose-diagram for number of linear structures in 5° about any given direction. Based on 1474 axial strike symbols on maps. The semi-circle in D 1—D 3 indicates the frequency 100. — D 2. Rose-diagram constructed like D 1. Based on 796 strike symbols for sub-vertical s-surfaces.

p. 17; Asklund & Thorslund 1935, pp. 47, 49; Hadding 1912, pp. 595, 596; Thorslund 1937, pp. 7, 24; Thorslund 1940, p. 57, pls. 13, 14; Thorslund & Asklund 1935, p. 8; Zenzén 1930, pp. 95, 96. — **24**. Du Rietz 1935. — **25**. Foslie 1957; Oxaal 1910. — **26**. Högbom 1925. — **27**. Du Rietz 1941. — **28**. Kulling 1933. — **29**. Beskow 1929. — **30**. Michel 1950. — **31**. De Munck 1951, (not the text figures). — **32**. Aleva 1950. — **33**. Marstrander 1911. — **34**. Bugge, J. 1948; Oxaal 1919. — **35**. Rekstad 1913.— **36**. Sjögren 1900; Vogt 1927, pp. 126, 128. — **37**. Holmquist 1900. — **38**. Kautsky 1953. — **39**. Foslie 1936; Foslie 1949. — **40**. Landmark 1951, map 3, p. 245 (only straight lines recorded by me, possibly somewhat subjectively). — **41**. Padget 1955; Vokes 1957. — **42**. Føyn 1937. — **43**. Kieft 1952; Mulder 1951; Uytenbogaardt 1953. — A few strike directions were obtained from each of the following sources that have not been used for the map: Budding 1951; Bugge, C. 1939; Du Dresnay 1950; Holmsen & Oftedahl 1956; Lakeman 1952; Oftedahl 1944, p. 195; Oxaal 1911; Törnebohm 1896; Zenzén 1927.

The paper of Kulling 1955 that also contains a compilation of lineations, for the Caledonides of southern Lapland, has been found to be very useful as a source of references.

The strike data are brought together in diagrams D 1—D 3. The diagrams show the number of strike observations in 5° about any given direction. One might also count the recordings in, for instance, 1 % of the periphery. The counter cell of 5° used in this case has the advantage that the interval 5° probably plays an important part in the field observations of many geologists in being the accuracy limit of their observations. Axes with a recorded strike difference of less than 5° may share a single actual strike. It can be argued that from this point of view the cell width 10° should be even more reasonable, but that would reduce the sensitivity of the method too much.

In the diagrams, there is a corresponding maximum or minimum, respectively, at 90° to each of the main maxima and minima. This is especially evident in the collective diagram, D 3, and is in good agreement with the theory that folds arise parallel, as well as at right angles, to a direction of main

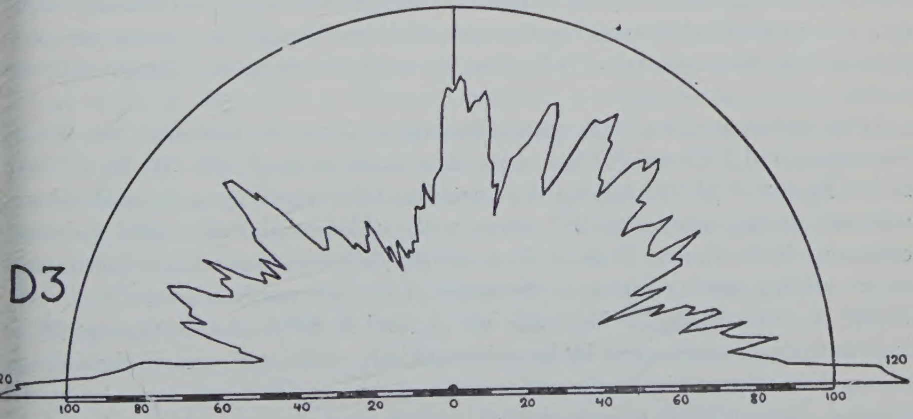

Fig. 3. — D 3. Rose-diagram constructed like D 1, fig. 2. Based on total material used for D 1 and D 2, 2270 strike symbols in all.

transport. If the maxima were determined chiefly by the geologist's tendency to group strike observations under headings like W, WNW, NW, NNW, etc., the chief maxima should be in W, N 67° W, N 45° W, N 22° W, N, N 22° E, N 45° E, and N 67° E. It is true that in D 3 we find very prominent maxima in W and N, but in N 66° W, N 23° W, N 25° E, and N 67° E there are instead very obvious minima. The NE and NW maxima are removed 2—3° in the same sense, anti-clockwise, relative to the expected positions in N 45° E and N 45° W. One must therefore conclude that the maxima are due largely to orientations occurring in nature.

The orientation of linear structures seems to support, rather than contradict, the hypothesis of deformation phases that differ in axial trend and range over the whole Scandinavian section of the mountain chain. Do axes of different orientations occur mixed up to the extent demanded by the hypothesis? Before trying to determine this, one may conveniently group the strike observations in orientation classes. The classes will be best delimited by the minima of the rose diagrams. The W class comprises strikes about W, from N 80° W to S 85° W, the WNW class strikes in N 53—79° W, the NW class in N 42—52° W, the NNW class in N 6—41° W, the N class in N 5° W—N 10° E, the NNE class in N 11—37° E, the NE class in N 38—48° E, and the ENE class in N 49—84° E. The map, fig. 1, shows the frequencies of the different classes in the source areas of the material. It seems evident enough that no single area has furnished the majority of axes within a certain class, and that most areas have yielded representatives of several orientation classes. So, one has the right to keep up the hypothesis.

It has been stated that lineations striking at right angles to one another are likely to belong to the same phase. For this reason, a further convenient grouping is possible. The N and W classes are called Group N, the WNW and NNE classes are called Group NNE, the NW and NE classes are called Group NE, and the NNW and ENE classes are called Group ENE. The westerly and northwesterly strikes are called by the customary term, transverse, and the northerly and northeasterly are called Caledonoid, the equally well-known term of Lapworth's. Each Group has thus one Caledonoid and one transverse component. The diagrams, D 1—D 3, allow us to characterize the Groups to some extent.

What strikes one first is the predominance of Group N, especially the W—E lineations (D 1). Group NNE has its chief maxima in N 69° W, N 62° W, N 20° E, and N 31° E. Among the lineations the transverse axes predominate, whereas among s-surfaces, D 2, those with Caledonoid strikes are the most common. With Group ENE it is a rather different matter, as Caledonoid strikes are the most common on the whole. The chief maxima are in N 38° W, N 28° W, N 8° W, N 52° E, N 58—60° E, and N 82° E. As for Group NE, it is most strongly represented by lineations, chiefly transverse ones. If the Groups are to be compared with the deformation evidence from my areas in north Sweden, Group NNE corresponds as regards strike to the oldest phase, the Palnoluokta phase. This correlation agrees well with the fact that this Group contains such a big proportion of transverse lineations. Transverse lineations (B' = *a*) should form the most readily at very intensive transport under great hydrostatic pressure. Such a transport is likely to obliterate traces of earlier deformations. Thus, if transverse lineations are formed during the last stages of deformation, it is probable that there will not be many other populations of axes left. It also seems that the last phases of an orogeny should decrease in strength, so the most intensive deformation is likely not to be the very latest. If, thus, the transverse lineations of Group NNE indicate an early age for this Group and support its correlation with the Palnoluokta phase, there is the question why the sub-vertical s-surfaces belonging to this Group (D 2) are not also as a rule transverse. The answer may be that the major s-surfaces (others are probably not recorded) were largely oriented during the final stages of the transports toward ESE. Before that, they were used as gliding-planes, and were effectively prevented from being rotated about B = *b*. But why, if the Group is an early one, do its s-surfaces dominate over those of other Groups? It is contended in LINDSTRÖM 1957, p. 14 & 1958 b, p. 7 that s-surfaces with orientations that are extreme in some way are likely to belong to late phases. Sub-vertical s-surfaces are indeed extreme and seem likely to be somewhat reoriented by any transport that is strong enough to form a set of fold lineations. This, I still maintain, is true in the regions of large-scale nearly horizontal thrusting. But a great deal of the material now discussed is from more central parts of the mountain chain, where the zones of vertical dip may reach very deep and thus be fairly persistent or resistant in any later deformation.

Group ENE can possibly be correlated with the somewhat later Trappsteget phase that saw development of many folds with Caledonoid strike. As for Group N, it corresponds in strike with the Raijkijokka phase. The predominance of lineations striking W may indicate that movement took place largely in the direction N—S. Group NE is hard as yet to identify with any of the deformation phases in north Sweden. Lineations with the strike of this Group surely abound in those areas, but even there, their age-assignment is somewhat problematic, as some of them may belong to a very early stage of the Palnoluokta phase and others seem to belong to the Trappsteget phase.

The Scandinavian Caledonides do not strike uniformly in NNE. In the SW and in the N, the strike is deflected to ENE. It would be interesting to try to find out, to what extent these deflections are due to the deformation phases discussed. If, for instance, the central part that strikes NNE is dominated by folds belonging to Group NNE, and the parts striking ENE are dominated by Group ENE, this may be evidence that the deflections are due to dominance of different phases. Textfigs. 4—6 were prepared in order to find out if there are any such relations. Textfig. 4 shows the quotient of the number of axes belonging to Group NNE divided by the number belonging to Group ENE for all areas where there are more than four strike signs belonging to either or both of the Groups. Where the quotient is less than 1, Group ENE dominates, and where it is more than 1, Group NNE is in majority. However crude the method may be, and however much it may depend on non-pertinent factors, it

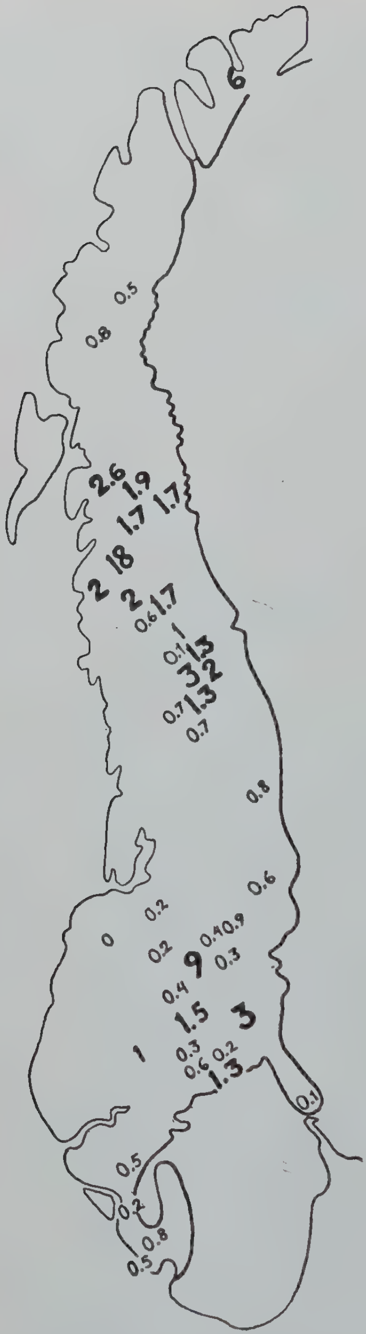

Fig. 4. — Quotient of Group NNE / Group ENE for the areas on fig. 1. Quotients less than 1 are shown by small-sized figures.

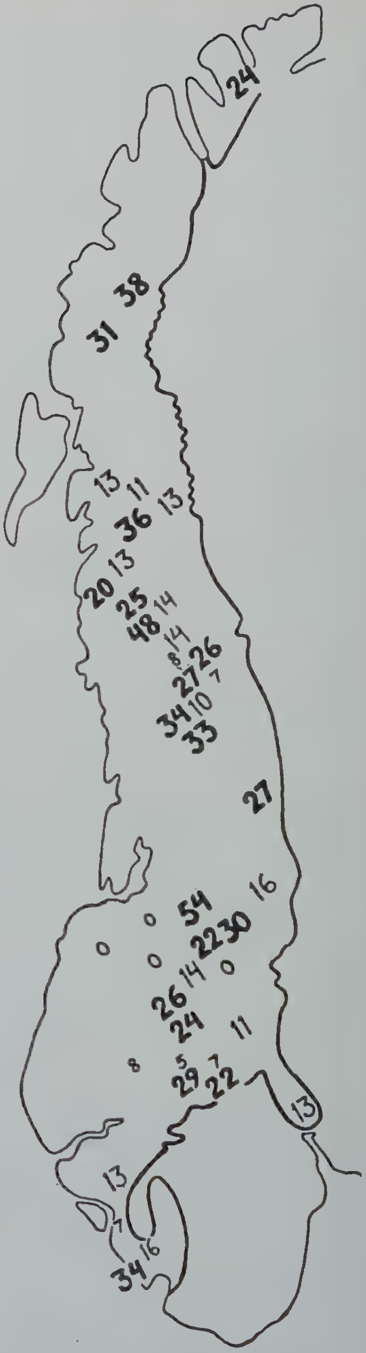

Fig. 5. — Percent strike symbols belonging to Group N in the different areas. Percentages of 20 and more are shown by big-sized figures.

still gives a rather convincing result. The parts that strike ENE are indeed dominated by Group ENE and those striking NNE are dominated by Group NNE, but — and this is most important — in any of the parts there occur streaks of areas with a majority of the other set of axes. In other words, the phases of deformation have had their effects along the full range of the mountain chain, but the later of the phases has had especially great effects in some belts, and these belts are now dominated by the fabric it imposed.

Fig. 5 shows how many percent of the axial records in each of the areas that are made up of Group N. The phase that formed this Group probably was the latest. It seems not to have had any profound effects on the general strike of the mountain chain. Its results are spread along the whole of the chain, with but a few areas here and there that have been strongly affected.

The relative frequency of Group NE, expressed in percent, is shown in fig. 6. It appears that these axes are not perfectly independent, but are largely correlated in space with Group ENE.

Some special implications of the hypothesis are worth discussing. Fig. 7 shows my idea of the fold systems. It is very generalized and to some extent a caricature. The breaks between the different trends are exaggerated and more angular than in reality. Many features are omitted, as each special interpretation at this stage may be as likely as not, to be wrong. The NW and NE axes are left out, as they are hard to identify in the general picture (some of these axes may belong to the very oldest). Each Group is represented only by two directions, one transverse and one Caledonoid, although in reality several trends exist at least in Groups NNE and ENE.

The Oslo area (fig. 1: 18) is dominated by Group ENE. Kiær (1901) made a detailed study of the distribution of facies in the uppermost Ordovician in part of the area and concluded that there was definite folding already during the deposition of these strata. Spjeldnæs (1957) confirmed Kiær's findings by discovering angular unconformities at the Ordovician — Silurian boundary. A long time after this episode of folding, the whole area, including the Silurian, became rather strongly folded. So, here is good stratigraphic evidence of different phases of Caledonian deformation. It is really interesting to note that according to Kiær's facies maps (1901, pp. 47—50) the late Ordovician folds do not strike in ENE, as do the post-Silurian ones, but in directions about NNE. Could Group NNE, and the Palnoluokta phase, be dated to about the end of the Ordovician?

The dominance of Group NNE in parts of southern Norway is largely found in low tectonic units (the Sparagmite nappes) that may, like the hard-schists in north Sweden (Lindström 1958a, p. 61), have obtained an early penetrative fabric and then kept it, possibly because they were less affected than the higher units by movements that came later.

Devonian strata in western Norway have largely been drawn into the Caledonian tectogenesis. Holtedahl (1953, pp. 455—486) gives a very useful summary on the Downtonian and Devonian in Norway. On the islands outside the Trondheim fjord, sediments as old as Downtonian are strongly dominated

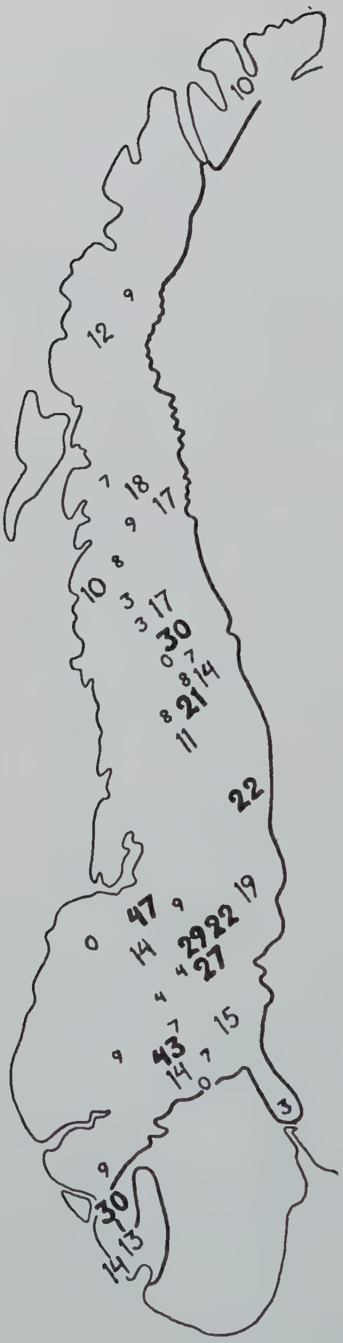

Fig. 6. — Percent strike symbols belonging to Group NE in the different areas. Percentages of 20 and more are shown by big-sized figures.

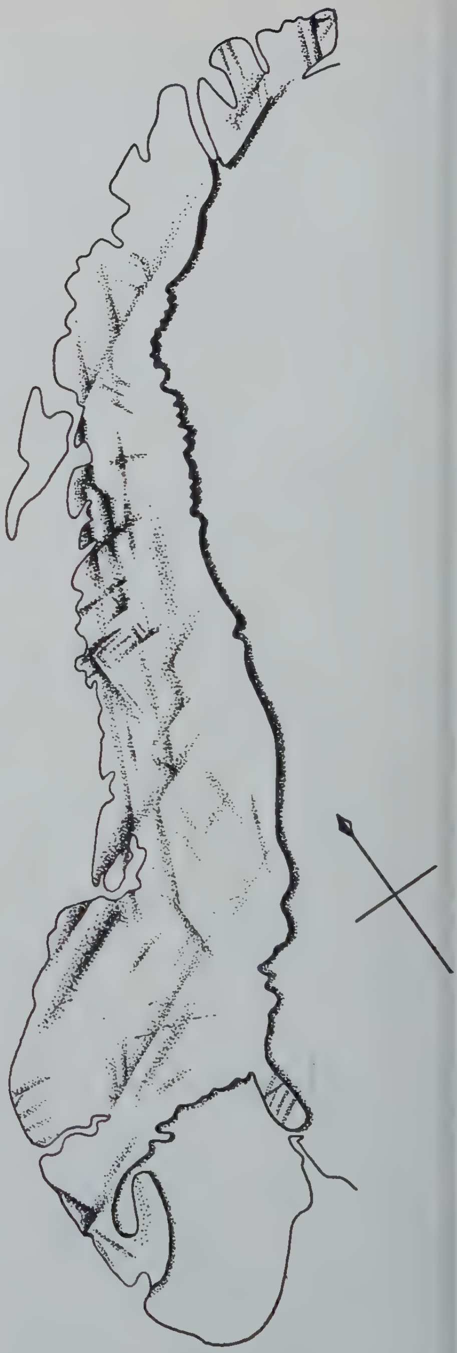

Fig. 7. — Diagrammatic representation of the fold-systems of the Scandinavian Caledonides, according to the author's interpretation. Thought of as illuminated from NW.

by Group ENE. Group N dominates in the Middle Devonian of western Norway, but there seems also to be some evidence of Group ENE (Bulandet, cf. op. cit., p. 471). The mostly non-metamorphic Devonian sediments largely rest on highly metamorphic Caledonian schists. Seemingly, erosion of the mountain chain must have worked down to this level before the deposition of the Devonian. For instance, at Gloppenfjord there is, close to the Devonian, an antiform of Caledonian metamorphics (KOLDERUP 1950, pp. 4—5). Most of the Gloppen antiform is a transverse structure belonging to Group NNE, but at its eastern end, the axial strike is NNW—N, which could be a deflection toward an early transverse strike belonging to Group ENE. On the other hand, as mentioned above, Group ENE appears in strength in Downtonian and Devonian rocks in the same areas. Seemingly, deformations producing Group ENE must have continued over a very long span of time, from sometime in the Silurian and well into the Devonian.

It is less astonishing according to my hypothesis to find conditions like those at the north edge of the Kvamshesten field, or W of Håsteinen, where, according to KOLDERUP's map (1928, pl. 1), Devonian strata with W—E strike rest on Caledonian metamorphics striking WNW, i.e., belonging to Group NNE.

Group N might have been formed any time in the final Caledonian stages after the early Middle Devonian. In the southern and central parts of the Scandinavian Caledonides, movement during this stage was probably largely toward S, or it would be hard to explain why W—E fold axes are so dominant. KULLING's Rödingsfjäll nappe (1955, p. 215) may have been finally put in its place by southward movement during this stage. From the area of this nappe, DE MUNCK (1951, figs. 9—11, 16) pictures N—S folds, that, in my opinion, have the characteristics of $B' = a$, i.e., they should have been formed parallel to the main transport.

Some of the general hypotheses on the Scandinavian Caledonides are not concerned with axial trends and are also not in conflict with my ideas. This is, for instance, the case with the one of KAUTSKY (1946, 1947), who maintains that there was first very large-scale thrusting in southeasterly directions, then strong "plastic folding" and granitization in NW. A modification of this hypothesis may well be compatible with the sequence of deformations for which I argue.

On the other hand, VOGT (1954 a & b) has put forward an explanation of divergent axial trends, according to which the strikes in the Scandinavian Caledonides were deflected to various degrees by wrenching along a continuation of the Scottish Great Glen fault. This, I must admit, is a very beautiful hypothesis in the sense that it unifies very much observation material, and in the further sense that it can bring about a great deal of research activity, because it is capable of being proved or disproved by studies on points that are vital to it. One such point is the sum of the fabrics of Devonian strata in western Norway. Further, detailed sampling of lineations and other small-scale fabric elements along any really extended sections from the Norwegian west coast and eastward might answer the questions if there is for all tectonic axes a constant trend of strike deflexion toward the coast, or if there is any identifiable set of axes that keeps the same strike all along the section. Only with a positive answer to the former question can Vogt's hypothesis be regarded as confirmed. Already, one can criticize parts of his hypothesis, although the criticism does not hit the core of it. For instance, Vogt (1954b, p. 43) pictures the transverse folds of the Otta valley as due to wrenching of originally Caledonoid structures, effecting a rotation by more than 90°. Now, Oftedahl (1950, p. 215) states that in the Rondane area, near the centre of Vogt's wrench structure, lineations of an ordinary transverse kind strike fairly constantly in WNW, which is what they normally do elsewhere at the same tectonic level, but which should not have been the case, had there been much wrenching. The same is the case at the very apex of the structure, in the Sel and Vågå map areas, where Strand's (1951, p. 28) diagrams show the usual concentration of transverse lineations about WNW—ESE.

Furthermore, Vogt's map (1954b, p. 43) shows the dominant strikes of major tectonic lines in southern Norway to be about due NE, which does not agree with the axial strikes compiled from publications. See this paper, fig. 4, and the map, fig. 1. It is rather more probable that most of the major structures strike about ENE.

Hernes (1957) has modified Vogt's trend map, and given an interpretation that seems to differ radically from that of Vogt. He states (p. 247) that the arcuation of the mountain chain may explain the diversity of axes. He further explains the arcuation as due to compression both from W and N (p. 249). This hypothesis also appears to be fairly complete. However, in stressing the northerly trend in westernmost Norway, Hernes does not take into account the diversity of axes that does exist there (cf. my fig. 1). Neither does he very much consider the strike trends in the metamorphic schists in the Caledonian substratum of the outliers of Devonian referred to above (p. 375). If the diversity of axes arose by a vice effect, by compression from W and N, we should probably find a dominance of either westerly or northerly axes in most areas, and axes of other directions should merely represent, at the most, the extremes of populations with their modes in W and N. There should not appear any other maxima in a large enough regional synthesis. Like Hernes, I believe that there was movement from N and W, but I do not believe that these movements had the regional importance that Hernes attributes to them.

According to Kvale (1948, pp. 7, 196—205) the diversity of axial trends may be explained by the principle that lineations may, under certain circumstances, form at almost any angle to the main direction of transport. The principle is probably true, and it may be one of the possible general explanations in cases where one finds a continuous scattering of axial directions. However, I believe that the principle cannot be used as the only explanation in cases where the axes are grouped about separate maxima.

It is evident that my hypothesis is in conflict with any assumptions of large-scale influence of pre-existing structural trends on the main directions of tran sport, cf. Holtedahl 1944, p. 21, and Landmark 1951. Such an influence is largely disproved by the conditions found in my areas in north Sweden and in SW Scotland. See Lindström 1958b, pp. 10—11.

With this paper, I have not meant to say that similar strikes in a very large region necessarily arose in the same phase of deformation. The inversion of this statement is more likely to be a general truth — that a certain stage of deformation gave rise, on the whole, only to a single direction of axial strike, or to two directions at right angles to one another.

It is much too early to formulate a theory on the formation of the Scandinavian Caledonides, let alone, on mountain-building in general. Meanwhile, we must try to be aware of all the possible hypotheses we can find, and help to collect reliable evidence. As a part of such efforts, the present paper should indicate some fields where it is important to increase our knowledge. See, for instance, the map fig. 1. The axial tectonics of the Oslo area want a painstaking investigation, and so do the fabrics of the Caledonian gneissic rocks of western Norway, as compared with the more phyllitic, largely overthrust tectonites. The tectonic axes in the key areas between the Trondheim fjord and the lake Storsjön are practically unknown, and very little fabric work has been done in the extreme north of Norway.

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Extremely Soda Rich Rocks in the Karelian Zone, Finnmarksvidda, Northern Norway

A Contribution to the Discussion of the Spilite Problem

By

T. Gjelsvik

Abstract. Greenschists and associated smaller beds of graphite schist and felsite, as well as intrusive rocks of diabasic and granitoid character, all belonging to the Karelian zone, show strong enrichment of albite, the soda content reaching 10 per cent. This soda prominence is discussed in relation to geosynclinal sedimentation and volcanism, regional and contact metamorphism, and other orogenic developments.

No positive correlation between soda content and the regional metamorphic grade was found, and since albite rich sediments were deposited more or less contemporaneously with the extrusives of the ophiolites, the albitization most probably occurred shortly after the consolidation of the flows.

As some of the intrusive greenstones, to which leucodiabases are related, are definitely late orogenic, and the granitoid rocks late or post orogenic, they are most probably derived from palingenic magmas whose soda richness is inherited from the spilites and the associated schists.

Introduction

The spilitic affinity of the greenstone series of the Karelic mountain chain has been discussed by various authors taking part in the geological exploration of the Swedish and Finnish parts of Fennoscandian Lapland (Sundius (1915), Geijer (1916), Eskola (1925), Hackman (1927) and Beskow (1929)).

Systematic geological surveys in the Norwegian parts of Lapland (Finnmarksvidda) were not undertaken until quite recently. In 1954 a team of geologists, of which I was a member, started to explore the western part of Finnmarksvidda. The abundance of albite-rich rocks within the area was noted and preliminarily discussed in the first paper published by the team (Holmsen et al. 1956). During my work in the westernmost parts of the area, albite-rich rocks were found to be spacially related to copper and uranium mineralization (Gjelsvik 1957, 1958 a). I therefore found it necessary to make a rather thorough petrographic and chemical study of them. Some data were presented at the 1958 winter convention of Nordic geologists in Finland (Gjelsvik 1958 b), but at that time the chemical analyses were not completed.

Description of Rock Series

GEOLOGICAL SETTING

The main geological units of the area investigated are granite, gneiss, quartzite, greenschist and quartz-mica schist. Many granitic and gabbroic intrusive bodies occur, mainly along the contacts or within the supracrustal rock series.

The rocks are folded, faulted and disturbed; the main structural trends bein N—S. These features, combined with a widespread overburden of glacia deposits, have made it difficult to determine the stratigraphic succession wit certainty.

A pre-Karelic unconformity is nowhere exposed, and if present at all, a intense late Karelic granitization (K-metasomatism) has probably removed th traces of it. In the gneisses near the contacts with the supracrustal rocks, relic of the latter are numerous. In the central gneiss area, however, relics of pre granitization rocks mostly consist of massive granodiorite and amphibolite, an also of some old-looking gneisses and migmatites. At the present stage of th investigations the possibility of pre-Karelic rocks in the central parts of th gneiss areas should not be excluded.

For details of the geological relationships the reader is referred to the publica tion of the team. In the following, detailed description is confined to th greenschist formation and the various albite-rich rocks.

THE GREENSCHIST FORMATION (ČASKIAS GROUP)

The greenschists represent a period of extensive basaltic volcanism in th Karelic geosyncline. They are preserved in several synclinal belts, the larges of which is the central zone covering the Stuorajavrre drainage basin. Thi greenschist belt is nearly 30 km wide, and is formed as a synclinorium with number of smaller synclines and anticlines. The best exposures are found in th NW on the Časkias mountain which has given name to the formation. In downfaulted block, including the Čaravarre mountain, some “argillite” an grit beds overlie and partly alternate with the greenschist. Elsewhere the green schists consist of a rather monotonous succession of schistose rocks, partly bande and frequently alternating with thin beds of limestone (dm—m thick, rarel exceeding 5 m), and a few thin beds of pelitic and carbonaceous materia Thick basalt flows or pyroclastic beds are rarely found, large amounts of th greenschists appear to be sedimentary layers formed by quick erosion of flow or pyroclastic beds, and consequent deposition, and possibly by direct depos tion of tuffs in water. The greenschists are generally highly schistose; howeve occasionally primary volcanic features are preserved. The least altered green stones are found near the Čarajavrre region. In the Časkias area the schists ar often isoclinally folded.

The main minerals of the *greenschists* are: hornblende, chlorite (frequent clinochlore), and albite. Quartz, calcite and iron ore may be rhythmicall abundant in the banded greenschists, and occur as odd grains in most othe types.

Generally albite occurs in very small, untwinned granules, often concentrate in bands a few mm or cm wide, alternating with chlorite and hornblende-ric bands of the same size. In most rocks hornblende and chlorite are needleforme (porphyroblastic), the former often concentrated in sheaves (fig. 1). In som layers, apparently original flows, scattered remnants of plagioclase phenocrys

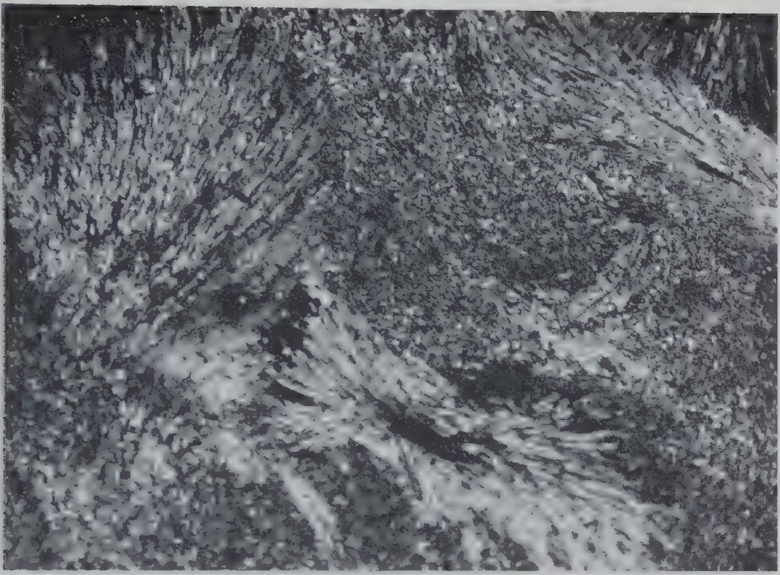

Fig. 1. Sheaf structure of hornblende in greenschist, C̄askias. Fine-grained matrix mainly albite. 15 ×.

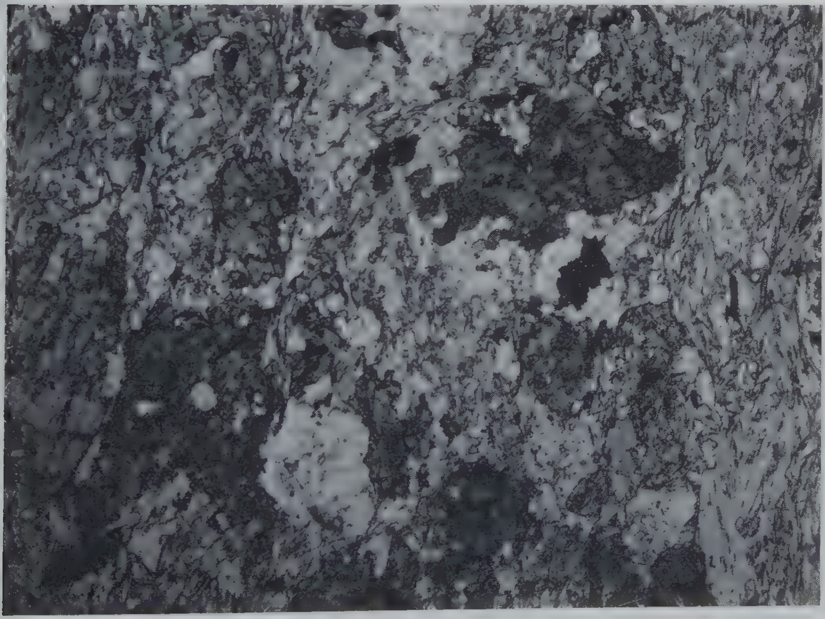

Fig. 2. Hornblende porphyroblasts and relic plagioclase phenocrysts in chloritic greenschist, C̄askias. 45 ×.

Table I. Greenschists from C̄askias

Weight per cent	1	2	3	4
SiO_2	46.80	46.46	51.02	55.39
TiO_2	0.90	1.14	1.08	1.37
Al_2O_3	13.62	17.30	14.55	16.52
Fe_2O_3	9.11	2.93	2.57	0.96
FeO	9.12	8.70	7.79	9.32
MnO	0.18	0.12	0.13	0.05
MgO	7.48	11.31	7.67	4.90
CaO	7.47	3.62	7.85	4.66
Na_2O	4.17	4.32	5.02	5.85
K_2O	0.25	0.20	0.10	0.12
H_2O^-	0.04	0.06	0.17	0.06
H_2O^+	0.92	3.98	1.41	0.69
CO_2	0.05	0.—	0.71	0.—
P_2O_5	0.16	0.18	0.13	0.09
Sum	100.27	100.30	100.20	99.98
Sp. g.	3.50	2.93	2.91	2.88
k	0.04	0.03	0.01	0.01

Modes	1	2	3	4
qtz				5
an_{10}	30	33	40	40
hbl	45	20	43	40
chl	12	40	10	*
ore	8	3	3	1
bi	1	2	*	1
sph	2	2	2	3
ep	1			
ap			*	*
carb			2	

* = present in amounts less than 1 per cent.

Niggli parameters

	si	*ti*	*al*	*fm*	*mg*	*c*	*co₂*	*alk*	*k*	*p*
1	117	1.7	20.0	49.5	0.56	20.0	0.2	10.5	0.04	0.3
2	104	1.9	22.7	59	0.64	8.7	0.0	9.6	0.03	0.3
3	122	1.9	20.5	47.7	0.57	20.0	2.3	11.8	0.01	0.3
4	153	2.8	26.7	43.7	0.46	13.8	0.0	15.8	0.01	0.2

Index.

No. 1 Coll. no. T7/234 Amygdaloidal greenschist, C̄askias E.
» 2 » » T7/238 Chlorite rich » » ».
» 3 » » T7/277 Flinty greenschist, Biddjovagge.
» 4 » » T7/281 Banded hornblende schist, Biddjovagge.

are observed. The composition of them is now albite, but small irregular inclusions of calcite indicate a previously calcic plagioclase (fig. 2). Some les altered greenschists have amygdaloidal structure, with a fine-grained matrix o lath-shaped albite and hornblende needles in a criss cross pattern (pilotaxitic) interstitial chlorite and epidote, and scattered phenocrysts of albite and hornblende. The amygdules contain one or more of the following minerals: hornblende, iron ore, epidote, albite and quartz.

Chemical compositions of the C̄askias greenschists are given in tables I an II. They are characteristically high in soda and very low in potash with variabl lime content. The types believed to be original sediments (nos. 4, 6—9) ar most extreme.

Table II. Greenschists and associated schists and felsite

	Caskias												Njallaav'zi		
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Na_2O	4.17	4.43	6.04	7.14	7.45	2.54	3.21	6.03	9.33	7.12	9.26	9.66	4.83	6.56	8.71
K_2O	0.08	0.15	0.11	0.09	0.11	2.00	2.59	1.46	0.19	0.66	0.13	0.16	4.54	2.71	0.12
k	0.01	0.02	0.01	< 0.01	0.01	0.34	0.35	0.14	0.01	0.06	< 0.01	0.01	0.38	0.12	0.01
Main minerals	hbl qtz ab/ol	hbl chl ab	ab qtz hbl carb	hbl ab carb	hbl ab carb	bi qtz ab chl	bi qtz olig	ab musc qtz graph	ab qtz graph	ab qtz	ab carb qtz ore	ab qtz carb ore	ab qtz bi micr	ab qtz micr ore	ab qtz
Accessories	ore ser	ore	ore bi chl		bi ore		chl	bi	tourm musc	bi carb (hbl)		bi hbl musc	ore chl	carb ser bi chl	rut bi ser chl ore

Index.
No. 5 Coll. no. T7/221 Fine banded greenschist, Stallovarre.
» 6 » » T7/254 Brown weathering greenschist, Časkias W.
» 7 » » T7/330 Banded hornblende schist, Biddjovagge, Caskias.
» 8 » » T7/319 Light coloured greenschist, » » .
» 9 » » T7/315 » » » » » .
» 10 » » T7/287 Mica schist, Biddjovagge, Časkias.
» 11 » » T7/288 » » .
» 12 » » T7/253 Graphite schist, Časkias W.
» 13 » » T7/358 » » , Biddjovagge, Caskias.
» 14 » » T7/306 Flinty felsite, » » .
» 15 » » T7/342 Banded felsite, » » .
» 16 » » T7/303 Felsite, possibly keratophyre, Biddjovagge, Časkias
» 17 » » S7/139 Felsite, bedded formation, Njallaav'zi.
» 18 » » S7/199b » , inclusion in carb. breccia, Siðosoaivi.
» 19 » » S7/176 » , » » » » , Njallaav'zi.

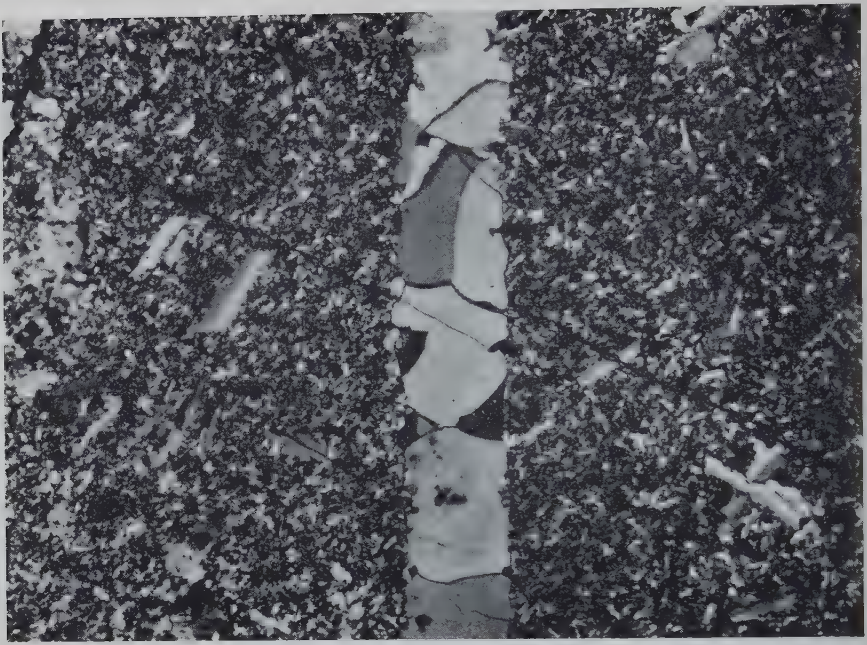

Fig. 3. Keratophyre structure in felsite. Časkias. 45 ×.

The interlayered pelitic beds always contain quartz and chlorite, and most of them also hornblende and a little albite. Biotite is found in varying amounts. The sheaf structure of hornblende is very conspicuous in some thick beds of a transition type of pelite and greenschist on the eastern ridge of Caskias.

Chemically the pelitic beds (table II, nos. 10 and 11) contain ordinary amounts of alkalies.

The mineral composition of the carbonaceous beds of the Časkias formation is not easy to decipher, owing to the dense graphite pigment and the fine grain-size of the other minerals. Apparently, albite, quartz and micas are the major components. A porphyritic structure is sometimes present.

The soda content of the carbonaceous beds is very high in both chemically analyzed beds (table II, nos. 12 and 13), the one from the ore zone of Biddjovagge being rather extreme in soda richness and potash paucity.

FELSITES[1]

Attending the graphite schist in the Biddjovagge anticlines are some highly crushed felsitic rocks, which serve as host rocks for the copper mineralization. In some rocks, the structures shown in fig. 3 are preserved, which, though more fine-grained, are like those of the leucodiabases, which will be described shortly. This felsite type may represent keratophyre flows. Chemically (table II, nos. 14—16) and mineralogically they are like the leucodiabases, and therefore might actually represent highly sheared leucodiabasic sills. However, rather fresh leucodiabases occur in lenses in the same zone, being apparently post-kinematic. Thus two generations of leucodiabases seem to be a prerequisite for this alternative. In other places the felsites are dense and even flinty, without any igneous texture at all. If not for the lack of graphite they could not be distinguished from the carbonaceous beds. Carbonate-banded felsite was also found in one place. Apparently both sedimentary and igneous material constitute this formation.

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[1] In this paper the term felsite is used for a dense quartzfelspar rock without genetic implications.

GRIT AND "ARGILLITE"

Detailed description of the field properties of this rock series is given by the Survey team (op. cit., p. 12—14) which applied the above terms. Only a brief review is given here.

In the region of Caravarre the greenstone is upwards interbedded with grey and brown lustrous schists, termed "argillite", which in turn are overlain by alternating beds of grit and "argillite" or siltstone of various types, including dolomite layers. Cross-bedding, ripple-marks, sun-cracks, and conglomerates demonstrate the shallow water origin of the series, and their orientation shows that the rocks are not inverted in this place. They are therefore younger than the greenstones.

The grit is mainly coarse sandstone with a pronounced clastic structure (rounded quartz in a very subordinate matrix of sericite and chlorite); the more arkosic and conglomeratic layers also containing microcline, perthite, quartzite, and felsite.

The "argillites" or siltstones are generally very fine-grained (< 0.05 mm), and accordingly a quantitative distinction between quartz and the two felspars is very difficult. Chemical analyses (table VI, nos. 34 and 35) show high amounts of sodium. A close mineralogical inspection by high magnification reveals that albite is very common, whereas microcline may, or may not be present. Quartz is always present, sometimes in a little larger grains than felspar. Some buff coloured types (fig. 4) contain great amounts of evenly distributed carbonate, while the grey types are poor in carbonate but rich in sericite, biotite and chlorite. Like the micas, iron ore (mostly hematite) is rhythmically distributed in fine bands. Though the rocks only show incipient metamorphism, it is difficult to find clearly clastic structures. Certainly all micas and chlorite are recrystallized, no primary "clay fraction" is observed (fig. 5), and also the carbonate minerals are recrystallized — as demonstrated by small cross-cutting carbonate veins and porphyroblasts. The fine-grained quartz-felspar mass has a structure of dubious (interpretation) character, which might be a close packing of clastic grains, but might just as well be a recrystallization (authigenic) structure. It should be noted that rounding of grains of this size is not to be expected.

Carbonate breccias were found at several places, the largest one in and near Njallaav'zi in the westernmost part of the area investigated, and in this pitchblende mineralization was detected.

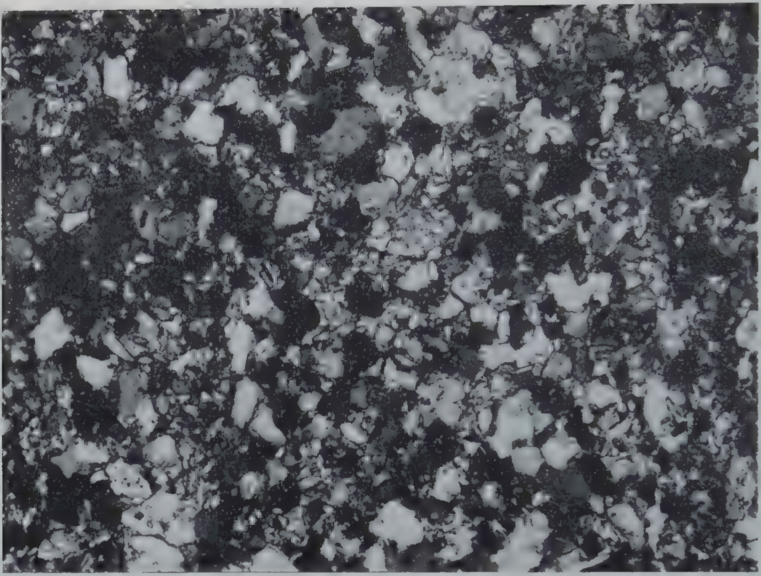

Fig. 4. Buff coloured »argillite»: albite, quartz, calcite, a little mica. 50 ×.

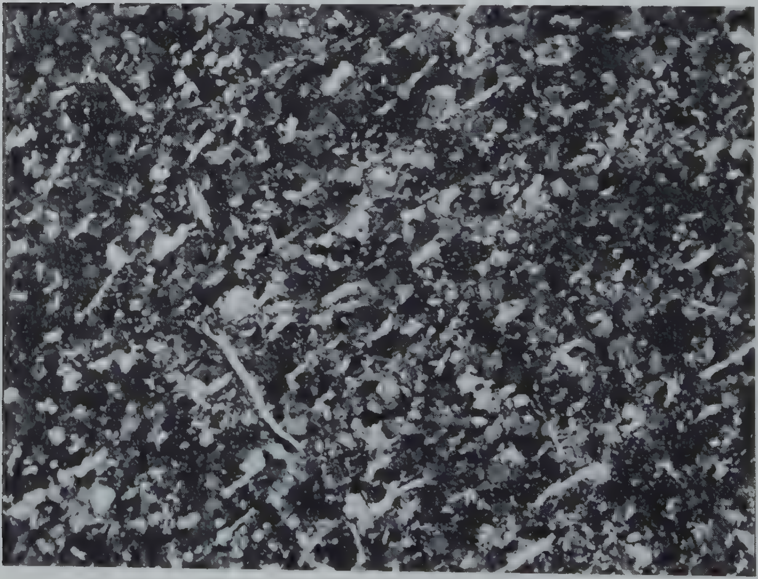

Fig. 5. Grey »argillite»: albite, quartz, oriented mica. 50 ×.

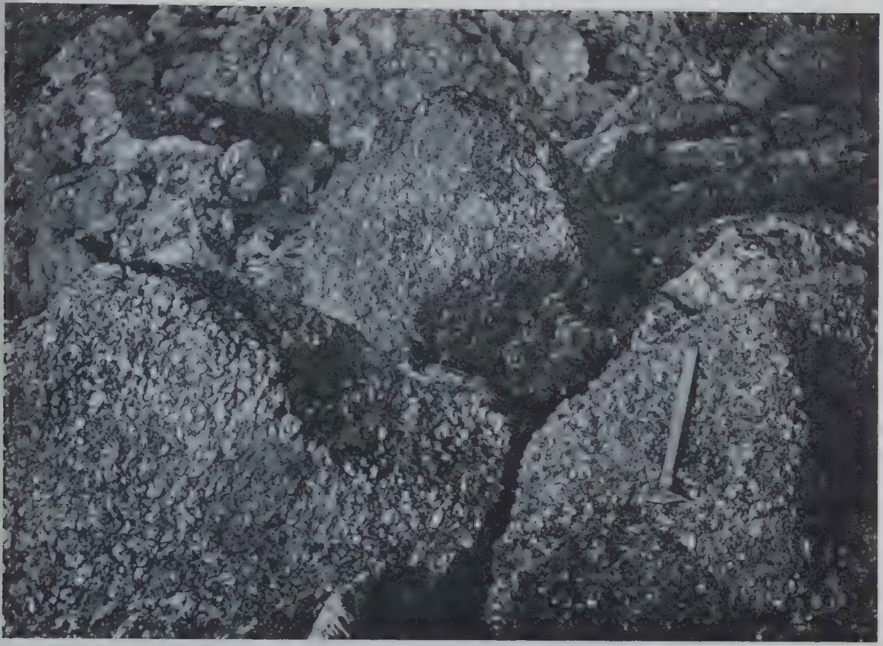

Fig. 6. Exposure of carbonate breccia, Siðosoaive.

The rocks have been intensely shattered, and subsequently replaced by carbonate (fig. 6). Most of the fragments of the breccias are greyish or reddish felsite, the origin of which was a puzzle until I undertook the microscopic study of the "argillite" of Čaravarre. The felsite is much like the "argillite", consisting mainly of fine-grained albite, quartz and carbonate, and with varying amounts of microcline. Mica minerals, however, are scarce. Besides hematite, tiny rutile crystals are a characteristic accessory of the felsites. The team also mentions the occurrence of carbonate breccia conglomerate in the argillites of the Čaravarre region (loc. cit., p. 12). In the field season of 1957 I studied the northern continuation of the Njallaav'zi breccia towards Rokkojavrre. In this direction the brecciation is less intense, and occurs in a bedded formation containing besides "argillite" of the Čaravarre type, also carbonate rich beds, and "argillites" which contain more mica minerals (fig. 7). The felsites of this type contain large amounts of alkalies, some extreme in soda and others also high in potash (nos. 16—19, table II).

INTRUSIVE GREENSTONES

Very often the greenschists contain long concordant lenses of greenstones with a diabase texture (fig. 8). Though the intrusive greenstones always are altered, they are much less so than the schists, and an age difference is most probable, if the intrusive rocks have not for some reason been more resistant to

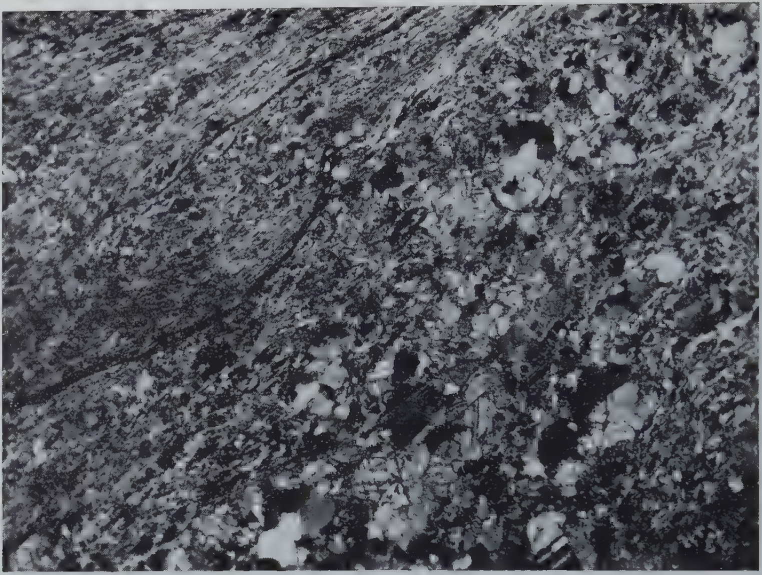

Fig. 7. Mica and carbonate rich layer in carbonate breccia, Siðosoaive. 50 ×.

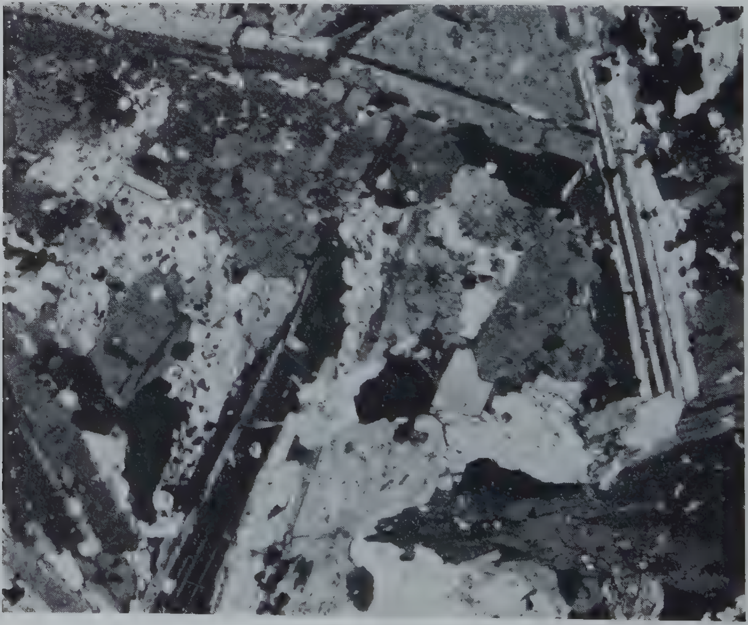

Fig. 8. Albite diabase: albite, hornblende, ore. C̄askias. 45 ×.

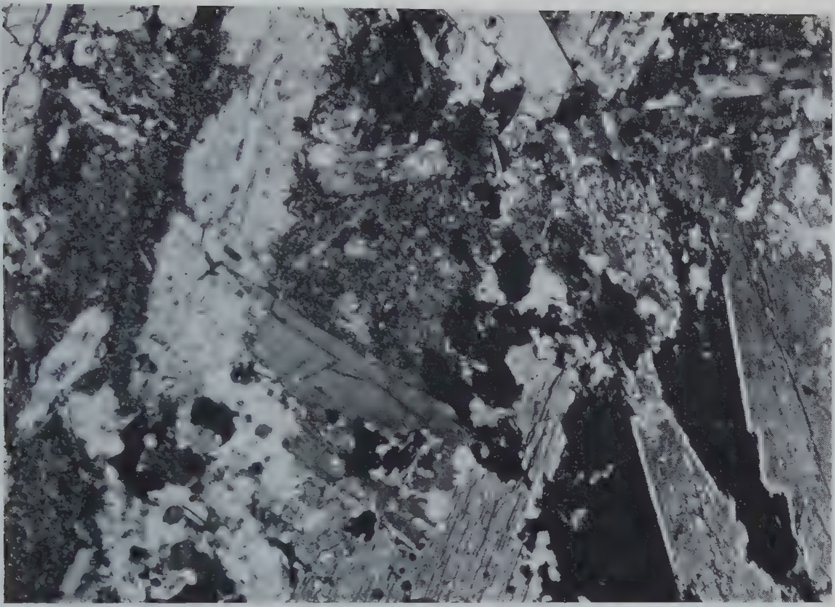

Fig. 9. Altered hornblende rich albite diabase: albite, hornblende (twinned), sericite and chlorite. 45 ×.

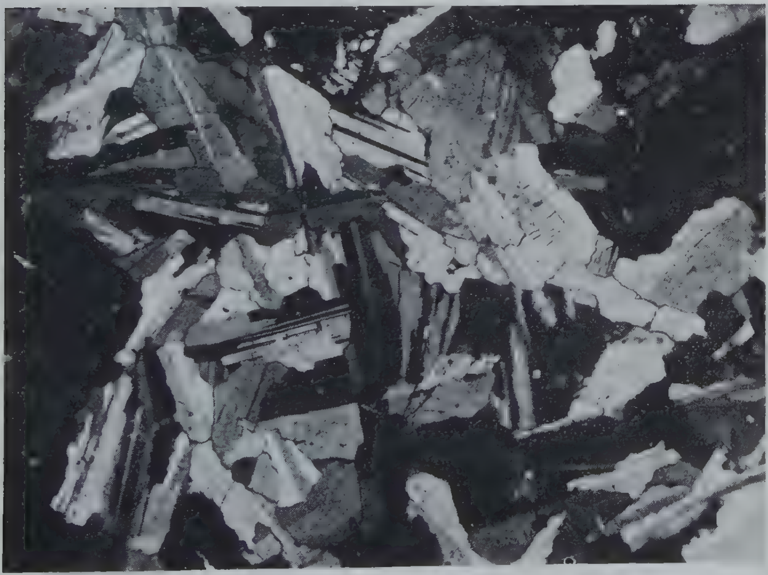

Fig. 10. Leucodiabase: nearly 100 % albite, 2 grains of ankerite at the top. Caskias. 50 ×.

Table III. Diabasic rocks

	20	21	22	23
SiO_2	49.20	51.08	46.65	57.88
TiO_2	1.43	1.19	1.60	3.57
Al_2O_3	13.29	12.95	13.39	16.11
Fe_2O_3	2.83	8.10	2.33	4.82
FeO......	11.88	6.51	4.23	0.50
MnO	0.16	0.05	0.11	0.01
MgO	6.59	5.75	4.57	2.02
CaO	9.58	4.69	9.15	3.33
Na_2O	3.06	6.10	7.07	7.96
K_2O......	0.31	0.28	0.12	0.27
H_2O^-	0.10	0.08	0.06	0.30
H_2O^+	0.96	0.80	0.47	0.63
CO_2......	0.65	0.76	10.32	0.00
P_2O_5	0.14	0.17	0.16	0.39
S	—	2.08	—	3.21
Sum......	100.18	100.31	100.23	99.80
Sp. g.	3.28	2.93	2.80	2.78
k	0.06	0.03	0.01	0.02

	24	25	26	27	28
Na_2O	7.32	7.53	8.00	9.49	10.35
K_2O	0.05	0.34	0.10	0.47	0.08
k	0.01	0.03	0.01	0.03	0.01
Sp. g.	2.67			2.69	2.66
Main ...... minerals	ab qtz hbl	ab carb bi	ab carb	ab bi hbl	ab
Accessories ..	chl ap rut ore	rut ore	rut ore	ep carb chl	carb ap ore

Modes					Niggli parameters				
	20	21	22	23		20	21	22	23
plag......	22	50	60	75	*si*	114	130	127	207
	(An_{20})	(An_{10})	(An_5)	(An_5)	*ti*	2.5	3.2	3.3	9.6
hbl	65	30	10	7	*al*	18.1	19.3	21.4	33.8
chl	5		*	*	*fm*........	50.9	51.0	33.2	25.3
sph	3	3	3	8	*mg*	0.45	0.43	0.56	0.43
ore	3	8	2	*	*c*	23.7	12.7	26.6	12.7
pt........		5	*	7	co_2	2.0	2.6	38.3	0.0
carb......	2	2	25		*alk*	7.3	17.0	18.8	28.2
bi........	*	2	*		*k*	0.06	0.03	0.01	0.02
ser				*	*p*	0.3	0.4	0.4	1.2
ap	*	*	*						

Index.
No. 20 Coll. no. T7/282 Hornblende rich albite diabase, Biddjovagge.
» 21 » » T7/329 Felspar rich albite diabase, » .
» 22 » » T7/326B Carboanate rich leuco diabase, » .
» 23 » » T7/305 Sphene rich » » , » .
» 24 » » T7/276 Fine-grained sill, » .
» 25 » » S7/126B Leuco diabase, Njallaav'zi.
» 26 » » S7/180 » » » .
» 27 » » T7/293A Porphyritic leuco diabase, Časkias E.
» 28 » » T7/324 Granophyric leuco diabase, Caskias E.

the dynamic metamorphism. Similar intrusive greenstones, though generally fresher and larger, occur in the quartzite and mica-schist formations, and the team even suggests a post-orogenic age for this group, separating it from the intrusive group associated with the greenschists (loc. cit., p. 50). The two groups are mineralogically, texturally and chemically so similar that I would rather suggest that they belong to the same (late orogenic) intrusive period. The main minerals are acid plagioclase (oligoclase-albite) and hornblende. Epidote, carbonate, biotite, chlorite, iron ores, sphene (leucoxene) and quartz

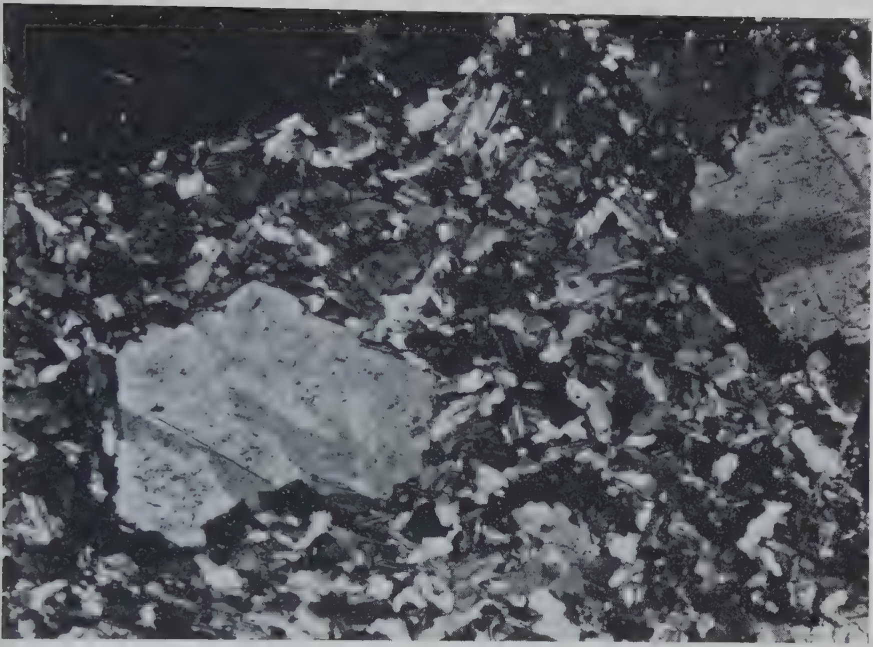

Fig. 11. Porphyritic leucodiabase. Časkias. 45 ×.

are present in varying, mostly subordinate amounts. Plagioclase is often sericitized and contains small inclusions of calcite or epidote, indicating an originally more calcic composition. In some less altered rocks the plagioclase may be An_{30}. In the best preserved rocks hornblende fills interstices between the plagioclase laths (ophitic texture), but during metamorphism it soon starts eating into and replacing plagioclase, and with progressive metamorphism the textural relationship is reversed: acid plagioclase, greatly reduced in amounts, fills interstices between chunky, elongated hornblende crystals (fig. 9).

Chemical analyses of the intrusive greenstones (table III, nos. 20, 21 and table VI, no. 41) demonstrate a rather high soda content.

This type of intrusive greenstone is called albite diabase by Fennoscandian students of Lapland geology, and I have adopted the term in this paper. Some of the albite diabases are primarily rich in hornblende, thus they grade into hornblenditic diabases.

However, another differentiation trend is more conspicuous. With decreasing amount of hornblende the albite diabase grades into leucodiabase,[1] the most extreme types of which are nearly pure albitites. Most often leucodiabase occurs in independent bodies, i. e. lenses or sills generally less than 10 m wide, or even smaller dikes. In these rocks albite generally forms divergently radiating laths (fig. 10), somewhat like the bostonitic texture (Johannsen 1931, p. 200). A porphyritic texture may be present (fig. 11), the phenocrysts sometimes being

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[1] The term given by Väyrynen (1938). A more correct term would be leuco albite diabase, but it is too long for frequent use.

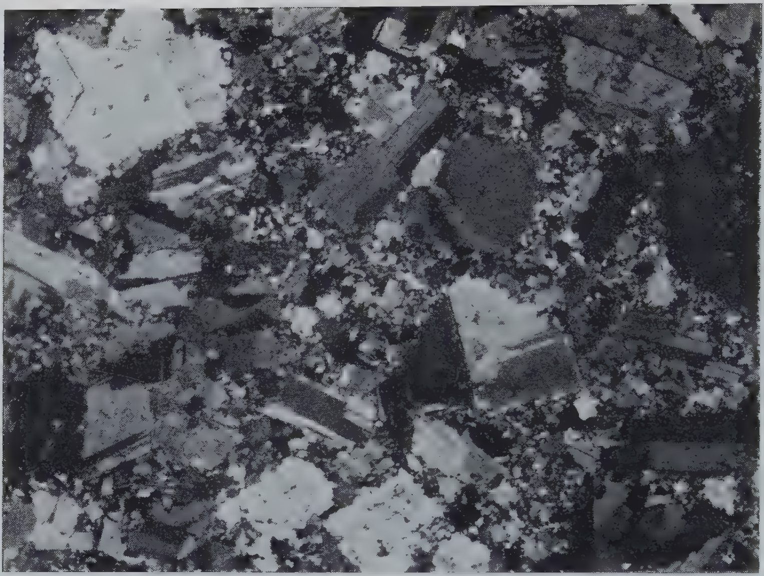

Fig. 12. Granophyric leucodiabase. Časkias. 15 ×.

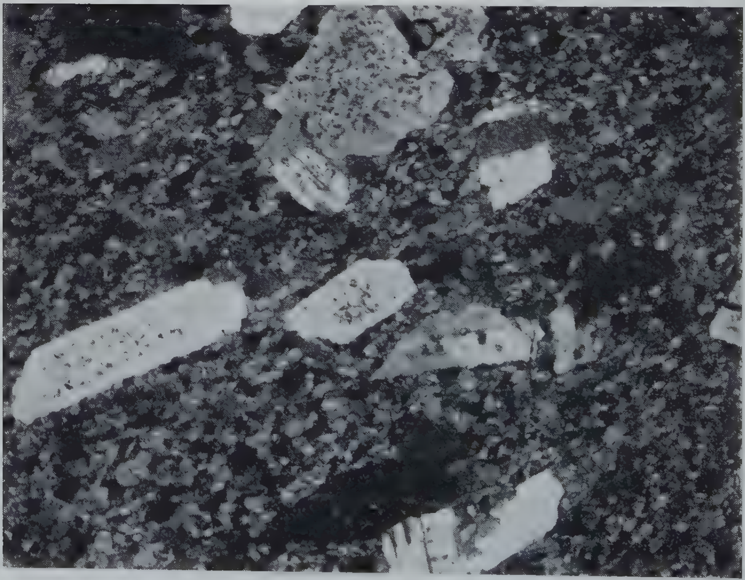

Fig. 13. Relics of albite laths in carbonate, replacement rocks. Časkias. 15 ×.

zonal. A granophyric texture was found in one or two leucodiabases (fig. 12). In one lense of leucodiabase, a marginal zone of some dm width consisted of flinty felsite identical with the type met with at the Biddjovagge deposit.

In the typical leucodiabases albite is by far the most abundant mineral, constituting 70—90 % of the rock. In the transition type hornblende is next in rank, but in the typical leucodiabases, hornblende, carbonates, biotite, sphene and quartz are equally *frequent accessories,* one of them usually dominating. In exceptional cases chlorite and epidote are formed, generally, however, albite is clear and fresh, showing no sign of decomposition. Its crystal outlines generally are sutured. The composition is now An_5, though the zonal phenocrysts must, of course, be a little more calcic. When quartz is present, it is always interstitial. The carbonate minerals (calcite and/or ankerite) may occur interstitially too, but commonly they are rhombshaped. Very often small carbonate veins penetrate the leucodiabase. In some places only a few, corroded albite laths occur in an otherwise ordinary carbonate fels (fig. 13).

The extremely high soda content combined with low potash of the leucodiabases is amply demonstrated in table 3, nos. 22—28.

QUARTZ-CARBONATE-ALBITE-SULPHIDE VEINS

A great variety of veins is seen cutting all types of greenstones and adjoining rock series. Most of them contain small amounts of iron and copper sulphides, some of them also magnetite. Very few (coarse-grained types) are rich in chalcopyrite and other copper sulphides, but are too small for exploitation. A detailed treatment of these dikes or veins is outside the scope of this paper. Most common gangue minerals are quartz, calcite and ankerite. In some fine- to medium-grained types albite is a main component (Na_2O content 8.52, K_2O 0.11, cf. HOLMSEN et al. 1956, table VI, no. 2) and albitization of the wall rock is a common feature elsewhere. Some carbonate dikes cutting quartz-mica schists near the bridge of Masijokka are worthy of special mention: the carbonate crystals, calcite and ankerite, are very coarse, and also large crystals or aggregates of a cobalt-rich pyrite occur. Adinole is found along the contacts. But for mineral composition, the dikes are similar to pegmatites.

Carbonate minerals, albite and quartz also occur as breccia fillings, irregular patches and joint fillings, commonly attended by copper and iron sulphides. Possibly exploitable copper deposits are located in favorable fold- and breccia structures in the Biddjovagge area, on the northern slope of Časkias.

SODA GRANITE AND ALBITE SYENITE

In their paper the Survey team describes two grantic bodies of definitely intrusive character, consisting dominantly of albite and quartz (loc. cit., p. 26—28). North of the Raisjavrre lake, forming the northern contact of the Časkias greenschist formation, a third body is located, showing the same features. Albite (An_{10-15}) makes up about 70 %, a moderate amount of quartz is

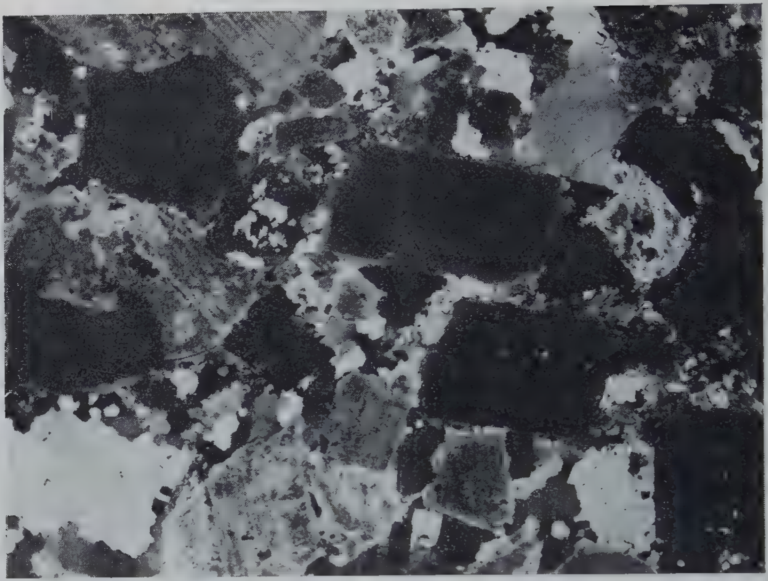

Fig. 14. Porhyritic soda granite. Slightly zoned feldspar. Stallovarre. 15 ×.

found in small, round crystals in the main body, while in some smaller sills in the greenschist quartz is accessorial, if present at all. The main body is massive, but in the sills, which may be slightly cross-cutting, foliation is common.

In thin dikes, and in the contact zone of the main body, the granite is porphyritic with weakly zonal phenocrysts of albite/oligoclase (fig. 14).

The Raisjavrre soda granite is clearly younger than the albite diabase, as apophyses from the granite penetrate the latter, which, in one place, has also been metasomatically altered to an impure talcstone along the contact.

Accessory minerals of the granite are hornblende, biotite (both somewhat chloritized), magnetite and microcline.

The primary origin of microcline is questionable as this mineral apparently replaces albite and is accompanied by myrmekite (fig. 15). Furthermore, the granite, going westwards across it, becomes more and more microcline-banded, and is finally completely incorporated in the regional-metasomatic granitic gneiss formed by a late- or post-orogenic potassium metasomatism. It is also cut by microcline pegmatites, probably associated with the regional granitization. This development is contrary to that described by GILLULY (1935) from Oregon, where intrusive, normal granite related to keratophyre and spilite has been subjected to sodium metasomatism.

All the three soda granites occur in, or very near, the contact of the greenschist formation. During a very detailed investigation of the Caskias region only one of the many granite sills was found to consist of normal granite.

Normal syenites were not found during the investigation. In two areas albite syenites of rather extreme types were encountered.

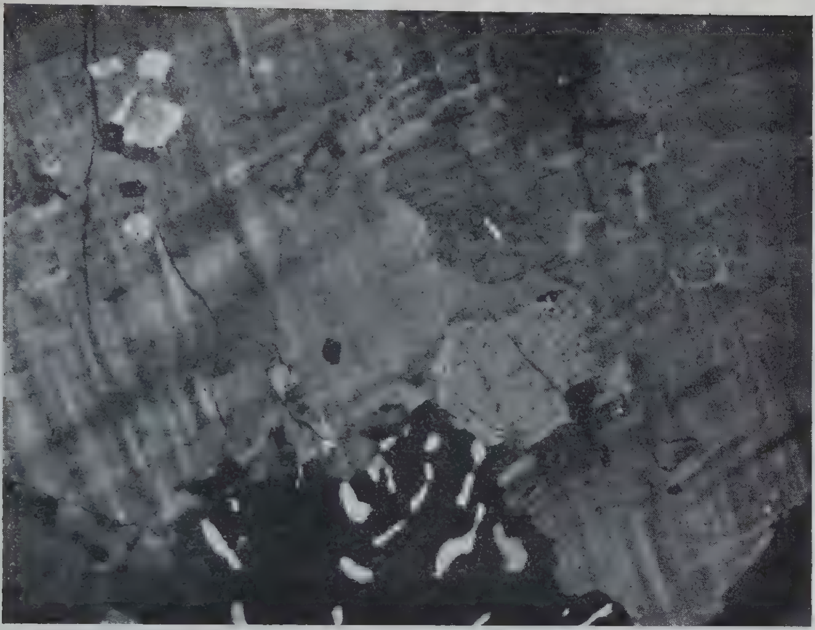

Fig. 15. Myrmekite and microcline replacing albite. Siednaljok. 45 ×.

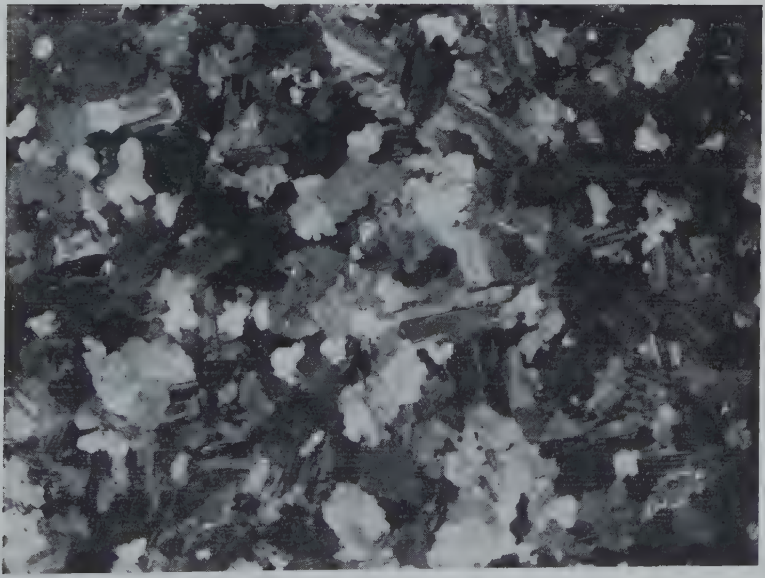

Fig. 16. Albite syenite vein in albite diabase. Njallaav'zi. 15 ×.

Table IV. Soda granite and albite syenite

Weight per cent	29	30	31	32
SiO_2	61.50			58.61
TiO_2	0.39			0.05
Al_2O_3	18.75			16.84
Fe_2O_3	2.97			3.22
FeO	0.93			0.92
MnO	0.02			0.03
MgO	1.68			1.44
CaO	3.89			5.12
Na_2O	7.44	6.25	8.25	9.23
K_2O	1.08	4.59	1.47	0.15
H_2O^-	0.26			0.14
H_2O^+	0.56			0.76
CO_2	0.40			3.43
P_2O_5	0.25			0.01
S				
Sum	100.12			99.95
Sp. g.	2.69			
k	0.09	0.33	0.1	0.01

Modes 29		Modes 32	
qtz	10		
an_{10}	70	an_5	88
micr	5	bi hbl	6
hbl	7		
bi	3	hem	2
ore	2		
carb	1	carb	4
sph	1		
ap			
zr			

Niggli parameters	29	32
si	215	197
ti	1	0.1
al	38.5	33.2
fm	19.3	18.0
mg	0.45	0.40
c	14.6	12.4
co_2	2.0	15.7
alk	27.6	27.7
k	0.09	0.01

Index.

No.	Coll. no.	
No. 29	Coll. no. T7/246	Soda granite, Niednjaljok, Časkias.
» 30	» » T7/230	Granite, sill, Gædasčokka.
» 31	» » T7/202	Soda granite, sill, Gædasčokka.
» 32	» » S7/156	Syenite, Njallaav'zi.

In the Njallaav'zi area albite syenites form dikes and sills, partly in albite diabase and partly in a breccia on the contact of granitic gneiss and greenschists (GJELSVIK 1957). In both cases the dikes are somewhat brecciated and replaced by carbonate. In the latter case the albite is coarse-grained (~ 2 cm), contains a little hornblende and biotite, and small amounts of other minerals related to a younger pitchblende mineralization. The texture is hypidiomorphic granular or granoblastic. The dikes in the albite diabase are more fine-grained and may exhibit a texture reminiscent of the leucodiabases (fig. 16).

In the Galanito area SW of Kautokeino, Pehkonen found a similar rock, but with more pronounced diabasic structure.

Chemical analyses (table IV) again confirm the sodium affinity of these intrusions. Potash is somewhat higher in the "granite" than in the basic intrusions, but the replacement character of microcline suggests that at least some of it was introduced later.

Discussion

In one of the most important contributions to the spilite discussion, GILLULY (1935) summarized and criticized the various theories so far proposed for the spilitization of greenstones. Though some important contributions have appeared subsequently it is convenient to start the discussion with a summary of the main conclusions of Gilluly, which are the following:

1. The spilites are not derived from independent "spilitic" magma suites, as originally proposed by DEWEY and FLETT (1911), but the peculiarities of the rocks may be of magmatic origin.

Table V. Average composition of igneous rocks of other areas

	I	II	III	IV	V
SiO_2	49.86	48.64	60.46	72.41	48.80
TiO_2	2.48	2.60	1.20	0.33	2.19
Al_2O_3	13.15	13.15	15.72	14.13	13.98
Fe_2O_3	2.55	3.47	2.62	0.89	3.59
FeO	10.58	10.68	3.62	1.17	9.78
MnO		0.25		0.03	0.17
MgO	7.05	6.45	2.52	0.44	6.70
CaO	7.98	8.13	4.28	1.36	9.38
Na_2O	3.17	3.26	4.40	3.30	2.59
K_2O	0.59	0.88	4.07	5.06	0.69
H_2O	2.30	2.10	0.78	0.67	1.80
CO_2		—			
P_2O_5		0.14		0.11	
O.e.	0.29		0.33		0.33
Sum	100.00	99.75	100.00	99.85	100.00
Number of anal	8	3	6	14	
k (Niggli)	0.11	0.15	0.38	0.50	0.15

I. Average "greenstone magma" of Lapland. E. MIKKOLA 1941, p. 260.
II. » composition of 3 albite diabases. » » , pp. 249—251.
III. » » » Lapland syenites (3 from Sweden, 3 from Finland). E. MIKKOLA 1941, p. 277.
IV. » » » late-kinematic granites. A. MIKKOLA 1949, p. 54.
V. » » » plateau basalts. R. A. DALY 1933, p. 17.

2. It is extremely probable that the albitization is not primary, but, rather, follows the complete consolidation of the rocks.

3. Authigenic hydrothermal agencies of albitization cannot be responsible for the large scale metasomatism of the spilites.

4. Neither regional saussuritization (SUNDIUS, 1915) nor albitization by heated sea water during extrusion (BESKOW, 1929) satisfactorily explain the spilitization.

5. A combination of Goldschmidt's theory of trondhjemitic differentiation, with Daly's theory of sodium concentration by the action of resurgent water (from wet sediments) most satisfactorily accounts for the features of the spilites and associated rocks.

In the world wide discussion of granitization which has been raging in the last decades, a theory of regional sodium metasomatism as an initial step has been proposed by several authors (e.g. LAPADU-HARGUES 1945, STRAND 1951). BEARTH (1952) found that a late- or post-orogenic albitization occurred in tectonically disturbed zones of the nappes of pre-Alpine crystalline rocks, which were included in the Alpine orogeny, and he relates this regional sodium-metasomatism to the spilitization of the Alpine ophiolites.

The highly altered state of the C̄askias greenschists does not allow any safe conclusion as to the time and nature of the albitization to be drawn from microscopical evidence. Worthy of note, however, is the very small size of the albite crystals in contrast to the porphyroblastic development of hornblende crystals. Scattered crystals of greater size are found only in some of the leas altered and less soda rich schists. They look "sick", and in my opinion they are best explained as decalcified plagioclase phenocrysts of the original lava, not a albite metablasts.

The problem, therefore, had to be attacked in another way, and chemica analyses, especially for soda and potash, have been performed on series' o samples from rocks selected from various metamorphic zones and stratigraphic formations.

The theory of a particular "spilite" magma, giving rise to the various albite rocks in Finnmark, finds very little support in table V, in which are reproduced analyses of igneous rocks from adjacent areas of Finnish Lapland. The average "greenstone" magma, representing 8 analyses, shows only a slight sodium enrichment from average "plateau basalts", and the average composition of 3 albite diabases, although slightly higher in soda, shows exactly the same *k* value as the plateau basalts.

Inspection of the chemical data of the Finnmark spilites shows that the important enrichment in soda is attended by a proportionally just as important reduction of potash. However, the latter element being of less importance than the former in basaltic rocks, the metasomatic changes expressed in Niggli-parameters, result in high *alk,* and extremely low *k*.

The reciprocal behavior of Na and K during the spilitization process leads to a regional separation of the two alkali elements, rarely matched by other geologic processes.

Calcium, which often is reported to be removed concomitantly with albitization of basaltic rocks of other areas, shows no consistent variation during the metasomatism of the Finnmark rocks (cf. the greenschists of table VI).

For such a widespread and large-scale albitization as that in Finnmark a theory of formation by regional metasomatism lies close at hand. The data in table 2, however, raise some important objections. Thus the pelitic beds, which commonly are first and most subjected to granitization, apparently have escaped the albitization best. The lack of porphyroblastic albite in the rocks, mentioned above, is another objection. Metablastic albites are characteristic for the regional albitization described by Bearth (1952) and by others. It may be said that both arguments are negative. However, if the albitization were related to the regional metamorphism, a positive correlation with the metamorphic grade would be expected. The greenschists of Caskias (tables I and II) all belong to one of the highest grades observed among the supracrustal rocks of the area and were assigned to the garnet grade by the team (loc. cit. 37, fig. 13), and in table VI are found chemical data for rocks from "lower chlorite", "chlorite" and "biotite" zones. Spilitic greenschists are found in chlorite zones and in the biotite zone (no sample of greenschist available from the lower chlorite zone). Greenschist of more normal composition is also met with. It is to be especially noted that the spilitic greenschist, no. 38, alternates with a phyllite, no. 36, of normal pelitic composition, confirming the evidence from table II, that the

Table VI. Rocks from various metamorphic zones

	Low chlorite zone			Chlorite zone			Biotite zone		
	33	34	35	36	37	38	39	40	41
SiO_2			67.03			50.18	47.17		54.63
TiO_2			0.53			0.96	1.28		2.18
Al_2O_3			13.89			15.12	13.57		13.85
Fe_2O_3			2.09			1.19	2.49		5.60
FeO			1.78			12.19	10.83		5.24
MnO			0.09			0.27	0.20		0.10
MgO			1.70			6.56	7.34		3.88
CaO			2.68			4.63	11.55		6.91
Na_2O	0.05	4.80	5.47	0.97	2.17	4.69	2.62	4.20	5.93
K_2O	0.33	2.43	1.72	3.18	0.29	0.17	0.42	0.14	0.71
H_2O-			0.09			0.10			
H_2O+			0.68			3.62	1.35		0.58
CO_2			1.88			0.29	0.95		0.23
P_2O_5			0.26			0.12	0.13		0.15
Sum			99.89			100.10	99.90		99.99
Sp. g.	2.65	2.82	2.67	2.68	3.04			3.05	
k	0.81	0.25	0.17	0.68	0.08	0.02	0.09	0.02	0.07
Main minerals	qtz	ab qtz micr	ab qtz micr carb	chl ?ab qtz ore	hbl ab chl ep/zoi	hbl ab chl	hbl ab ?qtz	hbl ab chl	ab hbl
Accessories	chl	bi ser ore	bi musc ore	ser	qtz	ep	carb ore	ore	sph ore ep

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No. 33 Coll. no. T6/7A Coarse grit, C̄aravarre.
» 34 » » T7/55A "Argillite", Gæsvarre.
» 35 » » T7/53 » , Guivevarre.
» 36 » » T6/3A "Phyllite", alternating with no. 4, Russogielas.
» 37 » » T6/18A "Typical" greenschist, Dagjeborre.
» 38 » » T6/4A Amygdaloidal greenschist, Russogielas.
» 39 » » T7/2084C Fine-grained greenschist, Gætkebakte.
» 40 » » U6/179 Greenschist or hornblende schist, Masijokka.
» 41 » » U6/104 Albite diabase, Biennejavre, Masi.

soda rich rocks belong to a particular *petrographic* series, namely the greenschists.

Furthermore, if albitization was related to regional metamorphism, the introduction of sodium would most reasonably take place from below — and the formations through which the emanations or solutions passed should also be albitized, if the PTX conditions were favourable for the reactions. Some doubt exists as to the stratigraphic succession in Finnmark. It is fairly well demonstrated, e.g., in the Agjet anticlinal area, that the C̄askias greenschists were deposited upon the quartzite formation (HOLMSEN et al. 1956, p. 16). A correlation of the Agjet quartzite and the Masi quartzite is very plausible, the latter apparently covering the quartz mica schist formation. The contact, however, is tectonically disturbed. At the present state of the investigation, the most probable succession is, from bottom up: quartz-mica schist, quartzite, C̄askias

Table VII. Rocks from lower strata

	Arkoses					Quartz-mica schists				
	42	43	44	45	46	47	48	49	50	51
Na_2O ..	0.48	2.09	2.94	3.58	5.80	2.32	2.77	2.88	2.94	3.46
K_2O ..	10.93	2.49	3.38	3.21	2.88	3.22	7.76	1.44	6.06	3.25
k	0.94	0.44	0.43	0.37	0.25	0.48	0.65	0.25	0.58	0.38

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No. 42	Coll. no.	U6/22	Kautokeino river, Masi.
» 43	» »	T8/157	Agjet, Kautokeino.
» 44	» »	T8/140A	» , » .
» 45	» »	U7/286	Kautokeino river, Masi/Miron.
» 46	» »	U6/33	» » , » .
» 47	» »	U6/53	Masijok, Masi.
» 48	» »	U7/289	Kautokeino river, Masi/Miron.
» 49	» »	U6/269	Masijok, Masi.
» 50	« »	U6/283	Biggejavre, Masi/Miron.
» 51	» »	U7/290	Kautokeino river, Masi/Miron.

greenschist, grit and argillite. The PT conditions existing during the metamorphism of the two lowest formations (biotite zone) should be favourable for sodium metasomatism. A series of alkali determinations has been carried out on samples from arkosic layers in the quartzites, and from the quartz-mica schists (table VII), rocks which ought to be susceptible to alkali metasomatism. The table demonstrates that some of the rocks are predominantly potash-rich, but most of them have *k*-values around 0.50. The average values of shales, according to Clarke (1924), are 1.31 % Na_2O, 3.24 % K_2O, and thus the Finnmark mica schists generally may be a little higher in soda. It may be a matter of argument whether the difference is due to primary differences (source-rocks, incomplete weathering, etc.), or to a slight sodium metasomatism. But it can safely be concluded that these formations have not been subjected to as intense sodium metasomatism as were the greenstones.

Summing up: the facts and indications brought out by the present investigation are not in favour of a regional sodium metasomatism as the main cause of the albitization of the greenschists of the Caskias group.

In a further study of the other sedimentary rocks interlayered with or overlying the greenstones, special attention has been given to the argillite and grit formation of the Čaravarre region. These rocks, according to Padget, who investigated the area, "are compact but lack metamorphic textures" (Holmsen et al., p. 36). Though the microscopic study I have performed of his specimens does not wholly confirm this statement, it must be admitted that the metamorphism is very feeble, and that a regional metasomatism of them is highly improbable. The albite grains, constituting the major part of the argillites (e.g nos. 34 and 35 in table VI), most probably represent detritus derived from the underlying greenschists, or authigenic recrystallization of such material.

Mention has already been made of the high albite content of the carbonaceous beds interlayered with the Caskias greenschists, but owing to the altered state of the rocks it cannot be said whether or not this is a pristine feature. It is therefore of interest to note that E. MIKKOLA (1941, p. 207—208), studying similar black schists in close connection with greenstones of the adjacent, less metamorphic areas of Finnish Lapland, considers the composition to be original, not a result of metasomatism.

The conclusion seems warranted that the albitization of the basaltic rocks occurred during or shortly after their outflow and consolidation.

Thus, this investigation has led to several of GILLULY's conclusions:

As the sodium richness of the Caskias greenschists neither can be explained as a derivative of an independent (spilitic) magma suite, nor as a product of regional metasomatism, it must be the result of post-magmatic, or possibly late-magmatic metasomatism. And rather than the submarine locus of the extrusions, it was the contamination of the magma by water from the wet geosynclinal sediments at deeper levels that gave rise to the spilitic development.

I cannot wholly agree, however, with the final conclusion of GILLULY (loc. cit., p. 346—348), summarized in point 5, p. 399 above. The theory of GOLDSCHMIDT (1922) for the differentiation of the trondhjemitic rocks, is simple and attractive, and theoretically correct, provided the water enriched magma is given time enough for fractional crystallization. This may, however, be questioned in the case of basaltic extrusion. Furthermore, biotite-rich, early differentiates ("opdalites") related to the spilitic rocks, are, if present at all, not abundant enough to explain the amount of keratophyres in many spilite provinces. The second effect of the water incorporated in the basalt magma, the formation of soda-rich "water gases" or solutions, which would modify the upper part of the basaltic magma and also albitize the extruded rocks, may also be questioned. GILLULY, in this respect, mainly adheres to a not very detailed theory put forth by DALY (1914, p. 339—340). DALY again, mostly relies upon a paper by BOWEN (1910), describing the development of albitic derivatives in a diabase sill. The question now to be asked is: why should a basaltic magma, assimilating water from sediments, particularly develop sodic, as contrasted to potassic, gases or solutions? To my knowledge, not many laboratory experiments have been carried out on this problem, and BOWEN himself has later arrived at conclusions which appear to be at some variance with his former idea:

"In an actual example the vapor formed at any point will move only a short distance before it encounters a cooler environment where it is partly or wholly condensed, becoming a part of the liquid there existing. Though a full and accurate analysis of such a complex situation is not possible, it seems necessary to suppose that a mass of intrusive rocks and its envelope, containing interstitially and in fractures a pegmatitic liquid that is experiencing "second boiling", will constitute itself a fractional-distillation column. Throughout this column there occurs a liquid through which gas bubbles slowly rise and suffer selective (fractional) condensation. Close to the boiling source the liquid will be continually enriched in the hyperfusible constituents that are relatively non-volatile, at points more and more remote the liquid will become increasingly richer in those hyperfusible constituents that are more volatile-water, various halogen compounds including acids, and the others. . . . . Such change of composition of the liquid as is due to loss of vapor tends to enrichment of the liquid in those hyperfusibles that are relatively non-volatile. Now, of the two alkali metals, sodium and potassium, the latter forms the more volatile compounds. As loss of vapor proceeds, the liquid is enriched in soda more than in potash. Eventually potash feldspar becomes unstable in contact with the liquid and is replaced by albite." (Bowen, 1933, p. 123).

Thus by addition of water to a magma, emanations richer in potassium than in sodium would be given off, which by escaping upwards would soak the above formations, including the basaltic lava already extruded. On the other hand, provided the theory is correct, sodium-rich rest-solutions may be formed in the magma chamber by this process, and could be squeezed out to form either intrusive trondhjemites or extrusive keratophyres — or hydrothermal albite (and carbonate?) veins. It is, however, somewhat difficult to understand how such residual solutions would be able to soak the overlying rocks to the extent necessary to form the widespread spilites. Quoting Barth: (1952, p. 221) "This liquid (in contrast to the expelled gases) is not a particularly potent agent of solution and alteration in the surrounding rocks into which it may escape."

However this may be, late- or post-magmatic metasomatism would most probably take place through the action of gases or emanations given off by the water enriched basaltic magma, and some reason must be found for the Na-metasomatism by such emanations. On their way upwards these emanations would have to penetrate large masses of geosynclinal sediments, many of which will be rich in clay minerals. The K-ions of the emanation will be adsorbed by the clay minerals (to form mica minerals) and the fluids finally reaching the basaltic flows may, in this way, change from predominantly potassic to sodic composition. Such "filtered" emanations or solutions could possibly carry out the large-scale albitization, and at the same time, being undersaturated in potassium, extract this element from the lavas.

From these theoretical, and somewhat hypothetical, considerations, I shall return to the Finnmark rocks.

Besides the greenschists and associated sediments, intrusive rocks also prove to be very sodium-rich, namely the albite diabase—leucodiabase series, and the albite granite—syenite series. The age of the former may be a matter of argument. Some albite diabases intruding the greenschist may be more or less comtemporaneous, and may then owe their albite excess to the spilite process. However, other albite diabases and the leucodiabases appear to be much less altered, and a late or even post tectonic origin may be postulated for them. If so, it is not reasonable to stretch the influence of the incorporation of water from wet geosynclinal sediments by basalt magma, belonging to the "Initiale Magmatismus", to the end of the orogenic period. In my opinion, these rocks do not owe their albite richness so much to metamorphic as to magmatic processes.

A magma of normal basaltic composition would not by normal crystal differentiation develop such extreme soda-rich rocks as the leucodiabases are. The very common carbonatization and scapolitization of the albite diabases, the carbonatization of the leucodiabases, as well as the hydrothermal carbonate-quartz-scapolite-sulphide veins related to the same rocks, prove that the magma must have been rich in volatiles such as H_2O, CO_2, Cl and H_2S. (Boron is also indicated by the presence of tourmaline in the rocks, especially in the hydrothermal veins.) The absence of potassium feldspar in the veins, and the general scarcity of mica minerals, indicate that the magma must also have been very poor in potassium. During the orogeny, remelting of the spilitic greenschists by palingenesis may yield a magma of such composition, provided the remelting could take place without considerable loss of the fugitive elements.

Most students of the leucodiabases of Fennoscandian Lapland agree upon an origin by magmatic differentiation (e.g. VÄYRYNEN 1938, ÖDMAN 1939, E. MIKKOLA 1941). PADGET, however, considers the "karjalites" — a term given by VÄYRYNEN and which includes the leucodiabases — as metasomatic rocks, formed by migration of elements and emphasizes their location in fracture zones (HOLMSEN et al., p. 48). He discusses a comprehensive group of albite-carbonate rocks, some of which are leucodiabases, others are metasomatic rocks. The hydrothermal activity following the albite diabase—leucodiabase intrusions includes albitization of the contact zones of the dikes or veins (adinole formation). In strongly tectonized zones, this sodium metasomatism probably could penetrate a longer distance from the source.

In my opinion, the textures of the leucodiabases demonstrated in figs. 10—12 are genuine igneous ones. It may be argued that the feldspar originally contained more anorthite. In one or two leucodiabases epidote occurs, particularly in some phenocrysts of albite. Ordinarily, however, epidote is completely lacking, and carbonate minerals, which frequently replace albite, do not form within the laths, but in the interstices or in cross-cutting veins, suggesting a late- or post-magmatic carbonatization.

The differentiation of leucodiabases some places occurred in situ, as shown by a gradational decrease of hornblende, accompanied by increase of albitic plagioclase in some parts of the diabase body. In Finland differentiation more frequently took place at depth, and the sodium enriched residual magma probably was squeezed out to form individual bodies.

An interesting relationship also exists between the leucodiabase and the soda granite—syenite group. As demonstrated by no. 23, table III and no. 29, table IV, they are nearly identical in chemical and mineralogical composition, the former being a little higher in titanium only. The only important difference is the texture of the rocks.

The soda granites definitely intruded late — are possibly even post-orogenic — and their especial soda-richness cannot possibly be ascribed to the early orogenic spilitization process. On the other hand, none of the sediments of the area are of a similar chemical composition, and thus a refusion, without some differentiation at depth, cannot be resorted to. Fractionation of a normal basaltic magma would eventually lead to a "eutectic" granite. A trondhjemitic differentiation in the sense of Goldschmidt is not probable either, as early or intermediate biotite-rich derivates are lacking. It is therefore suggested that the soda granites—syenites are the result of a deep-seated differentiation of a palingenic magma, formed at the expense of the spilitic rocks.

The differentiation process is similar to the one postulated for leucodiabases, but it occurred at deeper levels, and probably in a larger magma chamber.

Acknowledgements. The present investigation involved a lot of quantitative analytical chemistry and the wholehearted cooperation of the staff of the chemical laboratory of the Geological Survey of Norway is gratefully acknowledged. B. Brunn and L. B. Bolkesjö made most of the analyses, R. Larssen prepared the samples and made determination of specific gravity and CO_2.

P. Reitan kindly corrected the English text of the manuscript, and during preparation of the paper, he took part in discussions and made critical comments. E. Holmsen typed the manuscript.

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The pre-Quaternary Fossil-Bearing Systems Outside the High Mountains

Recent Results and Current Lines of Research within Phytopaleontology, Invertebrate Paleontology, and Historical Geology in Sweden

By

GERHARD REGNÉLL

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The present review is based upon a lecture delivered by the author on July 5, 1958, at the 7th Geological Convention of the Nordic Countries in Stockholm coupled with the celebration of the Centenary of the Geological Survey of Sweden. The original text has been slightly extended on a few points.

It is obvious that different principles can be applied in presenting a subject like the one to be dealt with below. As a matter of course, the substance of the account relates to results achieved by Swedish geologists and paleontologists working on the pre-Quaternary fossil-bearing formations of Sweden. However, in the author's opinion, national boundaries should not decide the range of our topic. Thus, reference will also be made to studies by Swedish scientists on foreign material or areas as well as to some studies made by foreign scientists on Swedish material.

1. Introduction

A hundred years ago, at the time of the organization of the Geological Survey of Sweden, little was known about the distribution and development of the fossil-bearing systems in Sweden, or about the fossils contained in them. This fact does not in any way detract from the credit of men like HISINGER, WAHLENBERG, SVEN NILSSON, DALMAN, and ANGELIN who were at work about the year 1800 and subsequent decades. The heritage passed to their successors is still living: The invertebrate paleontologists profit by their works to-day as formerly; the foundations of the current stratigraphy of the Cambro-Silurian in this country were laid by ANGELIN; and a remarkable stock of knowledge of the regional geology of the fossil-bearing rocks in Sweden was instituted by HISINGER.

A systematic investigation of the sedimentary rocks was promoted very decisively by the fact that the staff of the Geological Survey included a paleontologist right from an early date. The first holder of this post was GUSTAF LINNARSSON, appointed in 1869, who won international reputation by the high standard of his work. Centres of research beside the Geological Survey were and are, for natural reasons, the Swedish Museum of Natural History in Stockholm, and the Universities of Uppsala and Lund, later on also the University of Stockholm.

When, in 1946, the Geological Society of Stockholm celebrated its 75th anniversary, a series of reviews were published in the journal of the Society (Geologiska Föreningens Förhandlingar) in accordance with earlier tradition. These articles were intended to summarize the development within various areas of the vast field of the Geological Sciences under, say, the past 25 years. In a few instances a general history was given. Research relating to the Mesozoic of Sweden was accounted for by BRITTA LUNDBLAD (1946). Investigations into the High Mountains were treated in a special chapter by ASKLUND (1946). The progress of vertebrate paleontology was outlined by SÄVE-SÖDERBERGH (1946). Historical geology and paleontology were, seemingly, well attended to and were very much so in the particular fields covered by the articles just mentioned. But it is a fact that the Paleozoic systems of Sweden and their invertebrate faunas were quite ignored on that occasion. Where these are concerned, therefore, there will be reason to look beyond the past 12 years to which the present account will otherwise be appropriately confined. It must also be remarked in advance that an exhaustive record of the activity within the field of historical geology and paleontology in the period thus indicated cannot in any way be given within the frame of the present paper.

For convenience, the material will be grouped under three captions, namely Paleontology, Stratigraphy, and (very much condensed) Sedimentary Petrography and Sedimentology. A uniform presentation of these categories will not be aimed at. Needless to say, the lines mentioned do not run parallel but converge and intersect incessantly.

2. Paleontology

Scientists studying Swedish material of fossil plants are largely left to the Lower Mesozoic beds of Scania, S. Sweden. The basic studies on the Rhaetic and Liassic floras carried out by NATHORST or inspired by him were published far back in the past. It is obvious, therefore, that the need of a thorough revision asserts itself more and more. This became particularly evident following the observation by HARRIS (1937) that there is a close affinity between the Rhaetic and Old Liassic floras of Franconia, Scania (Skåne), and East Greenland. Contributions to a revision of this kind have been delivered by BRITTA LUNDBLAD, firstly in a comprehensive paper dealing with pteridophytes, pteridosperms, and cycadophytes from Rhaetic-Liassic beds in N. W. Scania (1950 a), secondly in a number of papers with a more limited scope (1948, 1950 b, 1954, 1958). B. LUNDBLAD has also worked on material obtained through deep-borings at Höllviksnäs (1949 a—b, 1956). This is also true of HORN AF RANTZIEN, who has pioneered in this country in studying pre-Quaternary charophytes and has presented results of considerable paleontological and stratigraphical interest. In the core Höllviken II, gyrogonites were found to appear partly sporadically, partly enriched in certain horizons, within the section 1,762—1,845.7 m representing Middle Triassic. The gyrogonites could be attributed to 11 different species which constitute a flora with points of contact with Younger Mesozoic charophytal floras. Its importance is enhanced by the fact that material which is younger than Devonian but older than Younger Cretaceous has heretofore been utterly scarce (HORN AF RANTZIEN 1953, 1954 a). HORN has also dealt with material from abroad and, further, has tackled general problems relating to charophytes (1951, 1954 b, 1956 a—b, 1957).

In this connexion it is appropriate to call attention to a few more micro-paleobotanical investigations. Some ten years ago we were very poorly informed about the nature of the vegetation which covered the land at the time of the formation of the Cretaceous sedimentary rocks of Scania. It meant a remarkable progress, therefore, when in 1949 NILS-ERIK ROSS published a preliminary account of an analysis of the content of pollen and spores in a Cretaceous clay which superimposes the kaolin at Åsen on the western shore of the bay Axeltorpsviken in Lake Ivösjön, N. E. Scania. *Gleichenia*-like ferns seem to have been the predominating floral element. Another plant, the spores of which strongly recall those of *Lycopodium cernuum* now living in the tropics, must also have been abundant to judge from the frequency of spores in the clay. It is much to be regretted that Ross was not granted to pursue a course which promised so much for the future.

Essential new information was brought by a paper by ASTRID CLEVE-EULER & HESSLAND (1948) which announced the discovery of a Tertiary series of strata at Åhus, N. E. Scania. A well-boring made at this locality had penetrated through a 34 m thick sequence of dark and light-coloured clays. These proved to contain a good many fossils, first and foremost diatoms and siliceous flagellates. By aid of the micro-flora the clay-sediments could be demonstrated to be marine, their age being Eocene. Until then, Eocene beds had not been known from the Swedish series of strata. There was no reason to question the primary position of the occurrence.

The appearance and significance of calcareous algae in the Paleozoic bioherms of Dalecarlia (Dalarna, N. Central Sweden) was first noticed by HADDING (1939, 1941). HESSLAND (1949 b) has published an interesting, predominantly paleo-biological study of boring and incrusting algae in the Lower Ordovician of the Siljan district.

In spite of their importance, papers by Halle, Florin, and Selling dealing almost exclusively with foreign material of fossil plants cannot be recorded here for lack of space. On the other hand, a few words ought to be said about finds of Hystrichosphaeridae in the Older Paleozoic of Sweden. These organisms are hollow spheres of microscopic size, their walls being made up of a cutineous matter. Their systematic position is open to discussion but in all probability they are to be interpreted as unicellular planktonic algae. These must have been very frequent in the Balto-Scandian seas in Ordovician and Silurian times. The first record of Hystrichosphaeridae in Swedish solid rock was made by Eisenack (1954 a), of Tübingen, Germany, who investigated samples of Upper Visby Marl (Upper Llandovery) from Gotland. A mass occurrence of a species of *Leiosphaeridia* in Ceratopyge limestone (Lower Ordovician) in Scania was reported by the present writer (Regnéll 1956 a). From Ordovician boulders in S. W. Finland, Martinsson (1956 b) described a form which was later called *Tasmanites martinssoni* by Eisenack (1958).

A survey of the recent development within pre-Quaternary phytopaleontology in Sweden would be incomplete without a reference to the Palynological Laboratory in Stockholm-Solna, founded ten years ago by Erdtman and directed by him. It goes without saying that the activity of the Laboratory in the first place concerns Recent and Pleistocene material. But pre-Quaternary investigations are also on the program, as can be seen from articles in "Grana palynologica" edited by the Laboratory.

Turning now to invertebrate paleontology we find that most groups relevant in this connexion have been subject to study in some way or other. Only sponges, bryozoans, and, to a certain degree, coelenterates and brachiopods leave something to be desired in this respect.

A methodical inventory of the presence of Foraminifera in the Paleozoic of Sweden has never been made. A short paper entitled "Upper Silurian Foraminifera of Gotland" was published by J. Smith (1915). Both descriptions and figures are so poor that they do not admit of any conclusion beyond the one that most of the so-called Foraminifera were bryozoans. Adequate information of Paleozoic Foraminifera in Sweden was first presented by Eisenack (1954 b). He recorded one species in the Ludibundus limestone (Caradoc) on the Island of Öland, ten species in the Upper Visby Marl (Upper Llandovery), and four species in the Slite Group (Wenlock) on Gotland, all of them agglutinating forms. Whether calcareous Foraminifera do at all occur in the Ordovician and Silurian of Balto-Scandia is uncertain. In view of the fact that, for good reasons, records of Foraminifera in Cambrian or Proterozoic beds are liable to be looked upon with a certain distrust, it should be pointed out that Foraminifera which are evidently genuine were found by Waern (1952) in both Middle and Lower Cambrian beds in the core from the deep-boring at Bödahamn, Öland.

The majority of the important papers on the foraminiferal faunas of the Cretaceous in Scania published up to now by Brotzen had appeared when, in 1946, Britta Lundblad surveyed the Mesozoic of Sweden and were included in her account. Subsequently, BROTZEN (1948) has studied the Paleocene Foraminifera. No additional data have been published about Foraminifera in the Lower Mesozoic of Scania.

By his eminent studies on Paleozoic corals, GUSTAF LINDSTRÖM founded a noted tradition in Sweden. This has been carried on to a minor extent only, viz. by TROEDSSON (1928) in describing Middle and Upper Ordovician material from Greenland, and by the present author (REGNÉLL 1941) in working up Siluro-Devonian coral faunas from Central Asia collected by E. NORIN, then Chief Geologist of the SVEN HEDIN Expedition. During the period under review, Cretaceous corals have been touched on only occasionally by TROEDSSON (1947 a). Otherwise, nothing has been produced in this field after HENNIG (1899) and BRÜNNICH NIELSEN (1918, 1922).

No group among the brachiopods has lately been treated monographically except the genera *Crania* (Cretaceous), by J. G. CARLSSON (1958), and *Ahtiella* (Ordovician), by HESSLAND (1949 e). BOUCOT (1957) paid attention to Swedish material in analysing the relation between the critical genera *Delthyris* and *Howellella*. Further, Paleozoic forms are discussed in various connexions in faunal descriptions and the like. JAANUSSON (1953 d) described a collection of brachiopods from the Tertiary of the Patagonian Cordillera brought together by E. LJUNGNER. HÄGG (1947 b, 1954 a—c) completed his inventory of brachiopods and molluscs found in Swedish Cretaceous localities.

Molluscs have received fairly ample attention in works by TROEDSSON (1951) on the so-called Höganäs Series (Rhaetic-Liassic) of Scania; by ISBERG (1934) on lamellibranchs in the Ordovician and Silurian reef limestones of Dalecarlia; by BERGENHAYN (1945 a—b, 1955) on Polyplacophora; by MUTVEI (1956, 1957) on nautiloids, his studies being based upon careful anatomical investigations (among previous papers on Paleozoic cephalopods it will suffice to call to mind such by TROEDSSON, particularly of 1926); by REYMENT (1955 a—b, 1956 b, 1957 a—b) on ammonites. In addition, REYMENT (1958) has published a paper of a kind not very common in the Swedish literature on invertebrate paleontology, namely an investigation, in part experimental, of the conditions of dispersal of fossil cephalopods. It may also be mentioned that REYMENT is working on a revision of the ammonites in the Lower Mesozoic of Scania. Finally, it should be remarked that a few papers on belemnites by JELETZKY (1946, 1948 a, 1949 a) were published in the Journal of the Geological Society in Stockholm (the present journal) and have a certain bearing on Swedish fossil material.

Also neozoologists have joined in the discussion of the phylogeny of the arthropods (HEEGAARD 1945, LINDER 1945). Particularly important contributions have been made by ERIK DAHL (1954, 1956). He points out the rôle played by different modes of taking in nourishment for the topography of the head. By following up this line of reasoning DAHL arrives at a simple and natural reconstruction of the original design of the crustacean head.

Especially two groups of arthropods have been studied extensively, namely trilobites and ostracods. Even in older times Swedish scientists contributed essentially to the knowledge of the trilobites. The position thus capture has not ben given up. Ontogenetic studies are embodied in papers by Westergård (1936), Fritz Kautsky (1945), and Temple (1952 b). Middle and Uppe Cambrian trilobites have been dealt with in fundamental and exhaustive work by Westergård (1922, 1936, 1939, 1946, 1947 b, 1948, 1950, 1953 a) who ha devoted more than 50 years of research to the Cambrian and the basal Ordovician. Minor contributions have been given by Thorslund (1949) and Tjernvik (1953, 1955). As to Ordovician forms, a fair number of special morphological and taxionomical investigations are now available, most of them carrie out by Jaanusson (1953 a—b, 1954, 1956 a—b, 1957 a). Others are b Whittington (1950) and Temple (1952 a). Of an earlier date are the monographs by Elsa Warburg (1925, 1939). It is evident that much importan information about trilobites can be derived from papers which are primaril concerned with stratigraphic objects. This is very true of papers by Tjernvi (1956; Lower Ordovician), Bohlin (1955; Lower Ordovician), and Thorslund (1940; the Chasmops Series of the Middle Ordovician). Troedsson (192 1937) worked up material of Middle and Upper Ordovician trilobite fauna from Northern Greenland collected by the Lauge Koch Expedition, and Cambro-Ordovician trilobites from Central Asia collected by the Sven Hedin Expedition.

American authors — most recently Christina Lochman-Balk & J. L. Wilson (1958) — have lately called attention to a certain affinity betwee American and Scandinavian trilobite faunas from the Upper Cambrian an the Lower Ordovician. This observation, and the telecorrelations and paleogeographical conceptions depending on it, presuppose a penetrating morphological analysis like the one performed in the papers quoted. In this connexion it will be proper to call attention to a remark by Henningsmoen (1958, p 180) bearing on the argumentation in his paper of 1957.

Thorslund (1940) was the first one to make use of an extensive materia of ostracods from the Ordovician of Sweden. In the great work by Hessland (1949 a) on the Lower Ordovician ostracods of the Siljan District, fu justice is rendered to the ontogenetic, biometrical, and variational aspects. Th effect of sexual dimorphism is also recognized. It will be fair to point out th work mentioned as standardizing and inspiring of the subsequent fertile researc in Sweden in this field. Later on, special papers relating to both Ordovician an Silurian ostracods have been published by Spjeldnaes (1951), Martinsso (1955 a, 1956 a), Jaanusson & Martinsson (1956), and Jaanusson (1957 b As in so many other fossil groups, useful and important data on ostracods ar to be found in faunistical or regional-stratigraphical publications. For the tim being, nothing is known about ostracods in Cretaceous and Tertiary rocks Sweden.

Remains of cirripedes are not uncommon in the Cretaceous of Sou Sweden. The material available has been summarized in a monograph by J. C Carlsson (1953).

The paleozoic echinoderms have been rather neglected for a lo time. The pioneer research by ANGELIN, BATHER, and JAEKEL in the 19th century was followed by a, practically, complete hiatus lasting to the middle of the fourties. An initial effort to bridge the gap was then made in that different groups were taken up for study: — Non-crinoid Pelmatozoa (REGNÉLL 1945, 1948 a—b, 1950 a—b, 1951); Ophiocistioidea (REGNÉLL 1948 b); Crinoidea (REGNÉLL 1948 c; UBAGHS 1956 a—b, 1958); Asteroidea (RASMUSSEN 1952); and Echinoidea (REGNÉLL 1956 b).

In the last few years a couple of papers relating to Cretaceous echinoderms have appeared (KÖSTER 1950, 1954 a—b, RASMUSSEN 1951, REGNÉLL 1955) but much remains to be done, especially where the echinoids are concerned. Tertiary echinoids from Patagonia collected by LJUNGNER were described by KÖSTER (1953).

In 1938, as is well known, KOZŁOWSKI published a preliminary account of his researches into dendroid graptolites from the Tremadoc of Poland. These investigations, when presented in an elaborate shape some ten years later, aroused the utmost attention and lead to a complete revaluation of the systematic position of the group. KOZŁOWSKI deduced that the graptolites were akin to the pterobranchs, as had been proposed earlier by some authors, and that they should preferably be ranked as a class of Stomochorda, *i.e.* not too far from the chordates. This view has won general acceptance. BOHLIN (1950), however, asserted the opinion that the agreement between certain structural features in the graptolites and the pterobranchs — first and foremost their possession of a complex stolon system — has no deeper significance. He vindicated WIMAN's opinion that the graptolites should be looked upon as a systematically isolated group which became extinct in Paleozoic times. Most likely, they were to be interpreted as a strongly specialized group of coelenterates. The idea set forth by BOHLIN has recently found a certain support by investigations made by DECKER & GOLD (1957). According to WETZEL (1958) electron-microscope investigations into the fine structure of *Diplograptus, Rhabdopleura,* and a few Recent bryozoans do not seem to corroborate the affinity supposed to exist between graptolites and pterobranchs. This matter of dispute will require further consideration.

In addition, contributions to graptolitology have been given, *i.a.*, by WAERN (in WAERN & *al.* 1948), BULMAN (1949, 1950), REGNÉLL (1949), and GLIMBERG (1952).

If there is reason to be in doubt of the systematic position of the graptolites, this is still more true in the case of certain other fossil organisms. Most important among those, due to their stratigraphic significance, are the conodonts. From an international point of view, these are objects of research of first-rate current interest. In Sweden, the conodonts have been attacked on a broad front by M. LINDSTRÖM (1954, 1955, 1957, and in LAMONT & LINDSTRÖM 1957). LINDSTRÖM has erected a great number of new species and made observations on the structure of the conodonts. His main object, however, has been a stratigraphic one.

Another group which is likely to play a rôle as index fossils in the Lower

Paleozoic are the chitinozoans, the nature of which is not safely established (presumably Rhizopoda, because of their thick pseudochitinuous te and marine habitat; cf. Collinson & Schwalb 1955). A first step towards thei being made use of in the Swedish series of strata has been taken by Eisenac (1955).

Under the caption "Problematica", or "Incertae sedis", finally, we have t range material described by Westergård (1953 b), Hessland (1949 c), an Regnéll (1947). Certain structures observed in Jotnian (Proterozoic) sandston (Ljunggren 1953, Lannerbro 1954) and suggested to represent traces of organ isms — and, if so, having a special interest as appearing in a rock of pre Cambrian age — are no doubt inorganic.

3. Stratigraphy

The purpose of the previous pages has been to give an idea of various side of paleontological research in Sweden. On the one hand, paleontological research has a value of its own, on the other, it provides the tools of a more an more refined stratigraphy.

Of unrivalled importance, from a stratigraphical as well as from a regiona geological point of view, are a number of deep-borings which have been sun into the Paleozoic rock-floor of South Sweden in the course of the past 2 years. It is true that the instances in which material and data from borings hav been placed at the disposal of scientific research are fairly rare — unfortunately, Sweden still lacks legislation in this field —, yet numerous enough as compared with those in older times. It goes without saying that almost all boring have had a practical aim. However, grants received from the Natural Scienc Research Council of Sweden (Statens Naturvetenskapliga Forskningsråd) hav enabled the Paleontological Institute of Uppsala to have three borings mad which were dictated by purely scientific interests (see also p. 418 below).

The first of these borings was brought down at Kullatorp on Mount Kinnekulle, in Vestrogothia (Västergötland), immediately below the contact betwee the Silurian rocks and the capping dolerite. In this way, a core was secure which comprised a complete sequence — ending at a depth of 88.56 m belo the mouth of the bore-hole — from Retiolites beds (inclusive) to Lower Chasmops beds (inclusive). This section of the classical Kinnekulle profile wa formerly unsufficiently known. The results were published by Waern, Thorslund & Henningsmoen (1948).

The second boring was made at Bödahamn, on northern Öland. It penetrate into Archean rocks at a depth of 162.16 m. The upper portion of the cor made up of Middle Ordovician Ludibundus limestone and subjacent beds, ha not yet been described. The Cambrian and the basal Ordovician have been dea with by Waern (1952) and Hessland (1955), the next higher members of th Ordovician (up to Platyurus beds, inclusive) by Bohlin (1955).

Thorslund (1958) has given a preliminary account of the third boring o the Uppsala Institute, finished in the fall of 1957. This boring was made o

Gotska Sandön, an island in the Baltic N. of Gotland. The Quaternary deposits were remarkably thick, 73 m. The surface of the rock-floor was formed by Palaeoporella limestone, of the Tretaspis Series. The entire Ordovician sequence below the zone of *Megistaspis gigas* of the Vaginatum limestone is wanting. This is also true of the Upper and Middle Cambrian and, possibly, of part of the Lower Cambrian. The boring ended at 241 m after having penetrated 9 m through a pre-Cambrian, maybe Jotnian, sandstone. The forthcoming complete description of the core will undoubtedly supply new and important information of the Paleogeography of the Baltic basin in older Paleozoic times, as evidenced by the first report now available (MARTINSSON 1958).

Also the Institute of Paleontology of Lund has been in charge of a couple of purely scientific borings, both in the classical Fågelsång area 10 km E. of Lund. One of these, at Lindegård, reached a depth of 59.72 m and penetrated through the Upper and Middle Dicellograptus shales. The core which was taken up in 1949 has been studied by GLIMBERG but has not yet been published. The other boring, made in 1954 at Koängen, was interrupted at a depth of 70.3 m after having penetrated through the lower part of the Tretaspis Series and its footwall into the zone of *Climacograptus haddingi* (formerly *C. putillus* HADDING, *non* HALL) of the Lower Dicellograptus shale. The core is being investigated by GLIMBERG, M. LINDSTRÖM, and R. NILSSON but the work is not yet finished.

As to other borings in Paleozoic areas we have to restrict ourselves to the following very summary statement: —

Quite a number of borings were made by the Geological Survey just before and during World War II in order to make an inventory of Cambrian and Lower Ordovician alum shales. The object of the borings was in the first place to investigate the content of oil and certain metals, first and foremost vanadium and uranium, in the alum shales in Scania, Vestrogothia, Östergötland, Nerike (Närke), and on Öland. The material from the borings has been treated from a stratigraphical point of view by WESTERGÅRD in a series of papers (1940, 1941, 1942, 1944 a—b, 1947 a). These have added to our knowledge of the stratigraphy of the Lower and Middle Cambrian and of the basal Ordovician, and have confirmed the stratigraphy established formerly by WESTERGÅRD for the Upper Cambrian. They have also contributed important data to regional geology.

Further, WESTERGÅRD (1936) has described a core from a boring 1933 at Mossberga, on Öland (deep of the boring 106.2 m, including oelandicus beds of the Middle Cambrian 40 m; Lower Cambrian 1.7 m; and pre-Cambrian quartzite and Archean rocks 58.4 m). A joint paper by WESTERGÅRD & THORSLUND (1938) presents the stratigraphic results of a boring made at File Haidar, on Gotland (depth of the boring 507.5 m; the boundary towards the Archean at 500 m).

A great quantity of cores secured in recent years by the Geological Survey rom borings penetrating through the uranium-bearing alum shales and adjacent beds in Vestrogothia have not yet been treated stratigraphically. They will ndoubtedly provide a fertile material, particularly for micropaleontological nvestigations.

From the Ordovician of Scania there are two more important borings, namely one from Fågelsång accounted for in great detail in a memoir by Hede (1951), and another one from Flagabro, in S. E. Scania. The core of the latter has been investigated and supplemented with field observations by Tjernvik. A report on the Tremadocian has appeared in the fall of 1958 (Tjernvik 1958).

A deep-boring in Lumparfjärden in the Åland Archipelago was discussed by Martinsson (1956 b), and another one at Gävle, 100 km N. of Uppsala, by Westergård in the description of the geological map-sheet Gävle (1939).

Deep-borings, indispensable as they may be, have certainly not deprived the time-honoured field methods of their importance. Studies based on such methods have augmented our knowledge of a number of Swedish Cambro-Silurian areas quite considerably. It may suffice to refer briefly to investigations in central Jemtland by Thorslund (1933, 1937 b, 1940, 1943, 1948 a); in Dalecarlia by Thorslund (1932, 1935, 1936 a—b), Isberg (1934), and Jaanusson and co-workers (Jaanusson 1947, 1953 c; Jaanusson & Martna 1948; Jaanusson & Mutvei 1951, 1953); in Nerike by Tjernvik (1952); in Vestrogothia by Thorslund (1937 a); on Öland by Regnéll (1942) and Bohlin (1949); in Scania by Malmborg (1955), R. Nilsson (1946, 1951, 1953), and M. Lindström (1953); and on Gotland by Spjeldnaes (1950) and Jux (1957), the basic stratigraphic investigations having been accomplished by Hede in mapping the Silurian of Gotland for the Geological Survey (descriptions of the geological map-sheets, and other publications from 1917, onwards). Tjernvik's monograph (1956) of the Lower Ordovician of Sweden was an excellent addition to the stratigraphic literature.

The Ordovician of Estonia was dealt with by Jaanusson (1945, 1956 c) and Martna (1957); of Åland by Martinsson (1955); and of Scotland by Lamont & Lindström (1957).

Great general interest is attached to the correlation suggested by Hede (1942) between the Silurian of Gotland and the standard British succession based on graptolites. This is also true of the corresponding discussion relating to the Middle Ordovician by Jaanusson & Strachan (1954).

A means of stratigraphic correlation which had been overlooked up to then but which can be applied especially to the Middle Ordovician series of strata was called attention to by Thorslund (1945, 1948 b—c, 1958, and in Waern, Thorslund & Henningsmoen 1948). He had found that bentonite beds have a wide regional distribution in the Ordovician of Scania—Bornholm. Subsequently, bentonites have been recorded from the Middle Ordovician of the Oslo area in Norway (Hageman & Spjeldnaes 1955). It is remarkable that the bentonite beds in the sequence at Sinsen (Oslo) could be correlated amazingly well with those in the section on Kinnekulle. The ashes from which the bentonites were derived are likely to have spread from volcanoes active in Middle Ordovician times within the British-Norwegian portion of the Caledonian geosyncline.

The Lower Mesozoic formations in N. W. Scania must be said to be relatively well known, first and foremost thanks to the numerous borings made by the

Höganäs-Billesholm Co. These were placed at the disposal of TROEDSSON, who in a monograph (1951) summarized his long experience of the Höganäs series. This monograph was preceded by a number of special papers and was followed by a few others (TROEDSSON 1947 b—c, 1948, 1950 a—b, 1954 b). A couple of substantial studies in the Mesozoic of N. W. Scania have been published by BÖLAU (1949, 1951, 1952, 1954); synoptic articles by HADDING, R. NORIN, and T. NILSSON are included in "Stenkol och lera" (Coal and Clay), 1953, a volume edited by Höganäs-Billesholm Co. The stratigraphy and fossils (mainly pollen) of a highly interesting isolated occurrence of, very likely, uppermost Rhaetic beds discovered recently at Sandåkra, 10 km S. of Hässleholm, will be dealt with in a forthcoming paper by T. NILSSON (1958). Detailed studies on the Upper Liassic series of strata in Fyledalen, S. E. Scania, have been carried out for a series of years by S. STENESTRÖM, but have not yet been published.

The most important event in Mesozoic stratigraphy in recent years is the realization of the deep-boring program for S. W. Scania projected by the Geological Survey. This has made possible the tracing of a much more detailed picture than before of the development and distribution of the Mesozoic rock-floor — and particularly the Cretaceous — within the area investigated. The geological results have been presented by BROTZEN (1945, 1950). BRITTA LUNDBLAD (1949 a—b, 1956) has contributed to the paleontological working up of the cores and was, *i. a.*, able to make the interesting statement that Rhaetic-Liassic beds are very likely present in the succession in S. W. Scania. Other contributions have been made by HORN AF RANTZIEN (1953) and ØDUM (1953).

A discussion of the division of the Upper Cretaceous has been carried on by JELETZKY (1948 b, 1949 b) and BROTZEN (1949 b—c), and the old matter of dispute concerning the geological position of the Danian has again been ventilated. By evaluation of the foraminiferal fauna, LOEBLICH & TAPPAN (1957) arrived at the conclusion that the Danian and equivalent formations should be incorporated in the Paleocene, while BRAMLETTE (1958), on the basis of his experience of the Coccolithophoridae, advises caution and refers to the influence of ecological factors. According to K. POŻARYSKA (1957), who has had an occasion to discuss with BROTZEN in this question, the beds containing *Crania tuberculata* should be referred to the Lower Paleocene. In a joint paper (BROTZEN & K. POŻARYSKA 1957) the authors mentioned deal with the Paleocene of Central Poland.

BROTZEN (1949 a) has accounted for the sparse exposures of Lower Danian in Scania. Beside his regional surveys of the mollusc and brachiopod fauna, HÄGG made some minor observations on the Cretaceous. Others are due to TROEDSSON (1954 a) and REYMENT (1954). REYMENT has also published papers on the Cretaceous of W. Africa (1955, 1956 a, 1957 c).

The Tertiary is very poorly represented in Sweden. Sedimentary rocks belonging to that system are found solely in a few localities in Scania. It is therefore hardly remarkable that the literature in this field is extremely scanty. However, two important papers were published 1948, namely by BROTZEN and by A. CLEVE-EULER & HESSLAND. Both have been mentioned above.

A material stratigraphic contribution on an international level was made by geologists attached to the last expedition to Central Asia under the leadership of SVEN HEDIN. The results have been presented mainly by E. NORIN (1937, 1941, 1946) and BOHLIN (1937).

4. Sedimentary Petrography and Sedimentology

Methods and investigations relating to sedimentary petrography were introduced in Sweden by HADDING who has described monographically various types of Swedish pre-Quaternary sedimentary rocks (1927—58) and, moreover, in that connexion provided a wealth of regional and stratigraphical data. A fresh volume, dealing with bedded limestones of the Cambrian and Ordovician, has recently appeared (HADDING 1958 b). After publishing his monograph of the Swedish reef-limestones, HADDING (1950, 1956) has commented again upon the Silurian reefs of Gotland. Recently (1958 a), he has discussed the mode of formation of the lithographic limestones.

HESSLAND (1949 d, 1953, 1955) has a weighty production in the field of sedimentology and sedimentary petrography. Thus, he has studied the Cambrian and Lower Ordovician in the core obtained through the Bödahamn boring; the Lower Ordovician of the Siljan area; and the Senonian in a core from a boring at Åhus, Scania, made in 1947—48 for the Paleontological Institute, Uppsala, at the expense of the Natural Science Research Council.

JAANUSSON (in BOHLIN 1955) has described the microlithology of the limestones in the portion worked up by BOHLIN of the core from Bödahamn just mentioned. In co-operation with MUTVEI, JAANUSSON has made a similar investigation of the Platyurus limestone in Dalecarlia (JAANUSSON & MUTVEI 1953). He has also devoted a study to the grain size in Ordovician limestones (JAANUSSON 1952). In this connexion, a paper by MARTNA (1955) should be mentioned in which he discusses the rôle played by shell fragments in the formation of certain calcareous rocks belonging to the Middle Ordovician Macrourus formation in Sweden. The mineralogy of Swedish Ordovician bentonite beds has been treated by ANN MARIE BYSTRÖM (1954, 1957).

Stimulating, obviously a bit too rapidly produced though, is an investigation of the Silurian reefs of Gotland and their stratified equivalents published recently by JUX (1957). The author rightly emphasizes the importance of full attention being paid to ecological factors and advocates an interpretation of the stratigraphy of the Silurian of Gotland which differs in important respects from that generally accepted (established mainly by HEDE). A Dutch geologist, A. MANTEN, has during two summer seasons been working on Gotland on problems similar to those treated by JUX but has not yet found time ripe to publish the results achieved. A preliminary report on investigations of Gotland reefs carried out by MANTEN and four other geologists from the University of Utrecht was recently given by RUTTEN (1958).

Mesozoic sedimentary rocks, finally, have attracted the attention of R. NORIN

(1949), Bölau (1951, 1954), Köster (1955), and Illies (1949). It goes without saying that numerous stratigraphic papers include pertinent facts on the quality and mode of formation of the pre-Quaternary fossil-bearing rocks in Sweden.

5. Conclusions

In an attempt to recognize the current trends in recent and present geological research in Sweden it will be apparent, where paleontology is concerned, that nowadays the individual scientist rarely undertakes to describe entire faunas with all different fossils included in them but rather concentrates on a given group of organisms of which he has thus command more or less as a specialist. It may be justly claimed that results of good international standing have been produced in this way. This is indicated also to some degree by the fact that several Swedish paleontologists have been invited to contribute to the "Treatise on Invertebrate Paleontology" directed and edited by Professor R. C. Moore.

An intimate knowledge of the several fossil groups is not only useful but indispensable to modern stratigraphy, which requires a much more refined discrimination of species than used to be needed formerly. Another tendency which favours stratigraphy is the increased interest for microfossils occurring in pre-Cretaceous deposits.

For the present, Cambro-Silurian stratigraphy centres fairly markedly round the Ordovician: its types of facies and paleogeography, and its correlation with Estonia on one hand, with Great Britain on the other. An interesting observation refers to the manifestation within extra-geosynclinal areas of Ordovician volcanism. In many such areas the volcanic activity can be traced as bentonite beds which by their regional constancy of horizon have the qualifications to be identified from one area to the other and, in consequence, to serve as stratigraphic index horizons. The stratigraphy of the Silurian, too, has been influenced by new ideas in giving increased attention to the importance of shift of facies. The Mesozoic stratigraphy has profited very considerably from the deep-borings in S. W. Scania.

The sedimentary petrography and sedimentology, which used to be badly neglected, have during the last few decades obtained a firm position in Sweden.

Finally, it deserves to be mentioned that the academic authorities of the geological branches at the University of Stockholm have recently taken an important initiative in founding a new series of memoirs, "Stockholm Contributions in Geology". The first volume (1957—58) has appeared. It comprises six memoirs, all of which belong to our sphere of interest. Accordingly, there is no reason to doubt that paleontology and historical geology will be able to furnish sufficient contributions also to this recent periodical.

6. References

For lack of space, the Bibliography includes only papers which have not been listed in the »Revue annuelle de la littérature géologique suédoise 1955» (G. F. F. 78: 579—618, 1956), or in preceding issues of that same review. This is inconvenient inasmuch as most papers referred to in the text by year of publication plus an index letter (a, b etc.) cannot be readily identified if published prior to 1956.

B. G. I. U. = Bulletin of the Geological Institutions of Uppsala, Uppsala.
G. F. F. = Geologiska Föreningens Förhandlingar, Stockholm.
K. F. S. F. = Kungl. Fysiografiska Sällskapets Förhandlingar, Lund.
L. U. Å. = Lunds Universitets Årsskrift. New Series. Section 2 (also Kungl. Fysiogr. Sällskapets Handlingar), Lund.
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Några urbergsstratigrafiska frågor i Norrbottens län

Av

PER GEIJER

Abstract: Some Stratigraphical Problems in the Precambrian of Norrbotten.

ÖDMAN's monograph of 1957 represents a very great progress in our knowledge of the Precambrian of northernmost Sweden, but on some points his conclusions appear to be in conflict with the evidence upon which earlier opinions were founded, so that one hesitates to accept them as definite. One point in question concerns the relations between the "Kiruna greenstones" (SUNDIUS 1915) and the Kurravaara conglomerate on one hand, and the ore-bearing porphyries of Kiirunavaara-Luossavaara on the other. The former, earlier regarded as conformably underlying the porphyries, are now instead referred to a later series. Evidence from neighbouring districts is adduced by ÖDMAN as a strong support for this view. It is here pointed out, however, that both the character of the conglomerate and the structural relations appear contrary to this conclusion, leaving the question at present open. Also are discussed the relations between the later Precambrian sediments of the region, the Vakko series, and the granites, the present writer maintaining that the earlier view, according to which of the latter only the Lina group is later than the Vakko series, still must be considered a well-founded alternative to ÖDMAN's opinion which implies that also the perthite granite and associated rocks belong to the granite group in question.

INLEDNING

Den framställning av Norrbottens läns urbergsgeologi, som nyligen har presenterats av O. ÖDMAN (1957), innebär ett mycket stort framsteg i kännedomen om urberget inom Sveriges nordligaste delar. Den som har egna erfarenheter från detta arbetsfält, av problemens komplexa natur och av de svårigheter, som alltjämt, alla tekniska framsteg till trots, möta vid fältarbeten inom betydande delar av detsamma, måste känna stor respekt inför det verk, som ÖDMAN och hans medarbetare nu ha slutfört. Det ligger emellertid i sakens natur, att när mycket nytt har framkommit och en del problem ha fått sin lösning, så ha samtidigt nya frågeställningar skapats, vilka peka framåt mot nya arbetsuppgifter. Detta är så mycket mera fallet som undersökningens allmänna mål blott i relativt ringa utsträckning har lämnat rum för speciella detaljundersökningar, i den mån de icke omedelbart ha tjänat det praktiska inventeringssyftet.

ÖDMANS framställning är förebildligt objektiv. Men en beskrivning av denna art måste, för att bliva läsbar, skildra det geologiska händelseförloppet med utgångspunkt från den tolkning av iakttagelserna, som författaren finner mest sannolik. Andra möjligheter få nämnas — så har också skett — men de bliva oundvikligen mera skjutna i bakgrunden. Vad som föranleder mig till det följande inlägget är önskan att ställa under debatt vissa stratigrafiska frågor inom den del av länet, över vars geologi jag tidigare har försökt en sammanställning (GEIJER 1931), i förhoppningen att de synpunkter som jag anför skola kunna vara av något värde vid fortsatta undersökningar inom området.

PAJALASERIEN OCH KIRUNAPORFYRERNA

När TRYGGVE ERIKSSONS undersökningar i Pajala (1954) hade resulterat i uppställandet av Pajalaserien såsom ett stratigrafiskt element, yngre än de järnmalmsförande porfyrerna, föreföll man att ha fått en uppslagsända, från vilken man borde kunna nysta upp åtskilligt av den trassliga urbergsstratigrafien i angränsande trakter. Dessa förhoppningar synas också ha förverkligats genom de fortsatta arbetena av ÖDMAN, ERIKSSON, FRIETSCH, FOLCKER, m. fl. Det är först när denna stratigrafiska uppfattning konfronteras med förhållandena inom det mest i detalj undersökta området, Kirunatrakten,[1] som svårigheter möta. Svårigheterna ifråga härröra från de senaste årens undersökningsresultat, som bl. a. innebära, att de tidigare av SUNDIUS (1915) beskrivna »Kirunagrönstenarna» och Kurravaarakonglomeratet skola tillhöra Pajalaserien och sålunda vara yngre än de överliggande porfyrerna, under det att man förut alltid har räknat med en normal lagerföljd, också utan väsentliga avbrott. I och för sig innebär ju den sålunda tänkta situationen ingenting orimligt eller ens osannolikt. Men när man går närmare in på bildens detaljer så finner man anledning ställa sig frågan, huruvida den presenterade beviskedjan verkligen är hållbar.

Grunderna för uppfattningen, att Pajalaserien är väsentligt yngre än de förmodat svioniska porfyrerna i malmtrakten, äro hittills endast rätt summariskt presenterade. Tydligt är likafullt, att denna uppfattning i allmänhet passar väl ihop med vad man känner om de båda enheternas fördelning inom området från Kalixälven i söder till Torne Träsk i norr, och att någon principiellt skild uppfattning skulle stöta på stora svårigheter. Vad åter beträffar »Kirunagrönstenarnas» hänförande till Pajalaserien, så synes också denna uppfattning starkt grundad, även om naturligtvis i dessa mycket jordtäckta trakter ett direkt sammanhang icke kan påvisas. Någon påtaglig svaghet i motiveringen för den nya stratigrafiska ordningen kan sålunda icke utpekas utanför Kirunatrakten. Låt oss då se närmare på konsekvenserna när det gäller denna trakts berggrund.

ÖDMAN har väl insett de svårigheter, som de nya stratigrafiska synpunkterna medföra där, och har ägnat saken en grundlig diskussion. Han tänker sig förhållandena omkring de nuvarande malmbergen vid Kiruna i lapponisk tid sålunda: De malmförande porfyrerna bildade en höjdrygg. På dennas västliga sida utgötos (subakvatiskt) Pajalaseriens basiska lavor. Ovanpå dem avlagrades sedan det flera hundra meter mäktiga Kurravaarakonglomeratet, här sammansatt till väsentlig del av material från de malmnivån underlagrande syenitporfyrerna i höjdryggen.

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[1] Det torde vara mest praktiskt att för naturgeografiska uppgifter behålla Kirunanamnet i dess ursprungliga betydelse.

Den tidigare tolkningen av Kurravaarakonglomeratet, framgången som resultat av Sundius' detaljundersökningar på Valkeasiipivaara och Pahtosvaara (1915), har ju varit den, att här föreligger material från eruptioner, vilka ha föregått den stora magmautgjutning av jämförlig sammansättning som har inlett porfyrserien i Kirunas malmberg; delvis har avlagringen tolkats såsom tuff i egentlig mening. Det kan vara lämpligt att som karakteristik av det dominerande vulkaniska inslaget i konglomeratet citera en sammanfattning som gjorts tidigare (Geijer 1931) och som därför är oberoende av dagens skiljaktigheter i synpunkter: »De underliggande grönstenarna äro representerade såväl av typiskt effusiva former som av hypabyssiska, ofitiskt struerade intrusioner. De utgöra dock endast en ringa del av materialet. Den alldeles övervägande massan, såväl bland bollarna som i de mera finklastiska partierna, består av mera saliska ytbergarter, nämligen albitofyrer[1] (delvis övergående uti mycket magnetitrika typer) och syenitporfyrer (Kirunas »liggväggsporfyr»), som utgöra nästa led i eruptivserien. De vanligaste formerna bland dessa äro dock sällsynta i konglomeratet. De utmärkas av en högre kalihalt och av mera pyroxen eller uralit, än vad konglomeratets vulkaniska material i regel uppvisar. I detta sistnämnda framträda så mycket starkare de albitofyriska leden, vilka icke spela någon större roll inom nästa etage. De i konglomeratet ingående albitofyrerna skilja sig även i strukturellt hänseende från de yngre. Enligt Sundius slipprovsmaterial, som förf. satts i tillfälle att genomgå, äro nämligen dessa bergarter i stor utsträckning karakteriserade därav, att grundmassans albitfältspat är utbildad i tunna tavlor, gärna trakytoidalt anordnade. Denna struktur har en viss släktskap med spiliternas. Den uti »liggväggsporfyren» vanliga strukturen, med fältspaten framträdande såsom kortare lister, regellöst anordnade och med komplicerade kornfogar, är dock även den representerad bland konglomeratets albitofyrbollar.»

Vad beträffar de av Ödman särskilt framhållna bollarna av magnetitsyenitporfyr, så tala dessa närmast för Sundius' uppfattning.[2] Visserligen finnas bland dem sådana som helt likna varianter av den mellan Luossavaara och Nokutusjärvi uppträdande magnetitsyenitporfyren, men andra former skilja sig starkt från dessa och visa, liksom de ovan såsom albitofyr betecknade bollarna, en tunntavelformig utbildning av albiten och därmed anknytning till spiliterna. Ännu mera markant är denna anknytning i sådana magnetitrika bollar, som också innehålla uralit med ofitiskt inneslutna albitlister (Sundius 1912), ett drag som återfinnes i »Kirunagrönstenarna» men som är absolut främmande för »liggväggsporfyren» och klart strider mot dennas natur.

Hela sviten av grönstenslavor och bollmaterial erinrar i högsta grad om

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[1] Uti ifrågavarande arbete undveks den så ofta missbrukade termen keratofyr, ehuru dessa porfyriska albitbergarter väl motsvara dess ursprungliga innebörd. I dess ställe användes »albitofyr».

[2] Bollar av apatitförande järnmalm, som också förekomma, äro så underordnade och till sin karaktär föga upplysande, att de svårligen kunna anses bevisa att erosionen vid denna tidpunkt hade berört de stora malmkropparna. Men bollarna utgöra givetvis ett viktigt observandum.

Bensons beskrivning (1915) av spilitiska pillow-lavor, doleriter och keratofyrer i devon i New South Wales, där keratofyrerna kunna bli så magnetitrika att de övergå i nästan ren malm. Det må också erinras om den i många olika länder och skilda system återkommande associationen av spiliter och keratofyrer. Det har därför fallit sig högst naturligt att föreställa sig en magmatisk utveckling från »Kirunagrönstenarna» över konglomeratets bolltyper fram till de former som representeras av malmbergens porfyrer. I alla händelser är huvudmassan av konglomeratets material så nära besläktad med de underliggande grönstenarna, att en härkomst från erosionsprodukter ifrån malmbergens porfyrer för dess del är praktiskt taget utesluten. Vissa former kunna dock, som sagt, härröra från dessa sistnämnda. Om nu dessa skulle vara så mycket äldre än konglomeratmaterialet i övrigt, så är det ju ett mycket egendomligt sammanträffande, att den nuvarande ordningsföljden ger en så naturlig bild av en magmatisk utvecklingsserie.

Ödmans uppfattning av stratigrafien och tektoniken är emellertid icke absolut beroende av hans föreställning om konglomeratmaterialets proveniens. Visserligen synes det osannolikt, såsom nyss framhållits, att detta material skulle tillhöra en helt annan geologisk cykel än de malmförande porfyrerna, men någon orimlighet innebär ej ett sådant antagande. Den största svårigheten, när det gäller att i detalj tillämpa Ödmans uppfattning, synes mig i stället möta när det gäller att prestera en stratigrafisk och tektonisk tolkning av den kända bergartsfördelningen i trakten.

Vad först beträffar själva kontakten mellan Kurravaarakonglomeratet och porfyrerna, så har denna tidigare varit blottad på ett ställe (Geijer 1910, s. 71). Dess utbildning uppfattades ej då såsom indikation på någon väsentlig förskjutning, och frågan om en sådan hade, med dåtida uppfattning av stratigrafien i stort, blott ringa betydelse. Numera har emellertid R. Frietsch, enligt vad han välvilligt meddelat mig, företagit en mera omfattande blottning på samma ställe och därvid kunnat konstatera, att gränsytan är ett förskjutningsplan med brant stupning mot nordväst. Detta är ju en i och för sig mycket viktig iakttagelse, men det synes knappast möjligt att av densamma draga slutsatser, som innebära en rimlig lösning av de stratigrafiskt-tektoniska problemen. Ödman har förut menat (1957, s. 64), att »då Kurravaarabergarterna antagits ha fyllt ut depressionen V om den gamla höjdryggen med de äldre bergarterna behövdes icke några rörelser av större mått för att dessa skall ha pressats ut över Kurravaarakonglomeratet och därigenom ha åstadkommit en skenbar överlagring». Från denna Ödmans utgångspunkt måste man nu, med hänsyn till den av Frietsch påvisade stupningen av förkastningsplanet, räkna med att i stället Kurravaarakonglomeratet (etc.) har skjutits upp på porfyrerna, sålunda en rörelse i motsatt riktning mot de markerade överskjutningarna i Vakkoserien Ö om malmbergen. Även om man räknar med »rörelser av större mått» synes en tillfredsställande rekonstruktion svår att prestera med utgångspunkt från den nu antagna stratigrafien, detta ej minst med hänsyn till lagerställningen i de båda berörda bergartskomplexen.

Den äldre uppfattningen av stratigrafien grundade sig ursprungligen på de förhållandet, att lagerföljden av grönstenar, konglomerat och porfyrer ansågs alltigenom visa konformitet i strykning och stupning. Konstaterandet av förkastningen emellan konglomerat och porfyr berör ej det ytterst viktiga faktum, att lagerställningen inom de olika leden är fullt enhetlig; i varje fall är det tydligt, att om någon avvikelse i stupning över huvud taget föreligger emellan porfyrerna och den underliggande Pajalaserien, denna vinkeldiskordans måste vara så obetydlig att den saknar stratigrafiskt och tektoniskt bevisvärde.

Om, såsom synes sannolikast, porfyrserien uti lapponisk tid icke längre befann sig i horisontellt läge, måste ju en vinkeldiskordans ha förelegat emellan densamma och den förmodat yngre Pajalaserien. Därav följer också, att förskjutningen måste ha åstadkommit den nuvarande (ungefärliga) parallellismen emellan de båda seriernas lagerställningar. Saken blir för övrigt ingalunda enklare, om man antager att porfyrerna under sagda skede ännu intogo ett approximativt horisontellt läge. De tektoniska förändringar, som den nya stratigrafiska uppfattningen förutsätter ha ägt rum, måste därför vara skäligen komplicerade, och den nuvarande bergartsfördelningen kan icke förklaras utan att man räknar med sådana rörelser »av större mått», som hittills kända fakta förefalla att utesluta. Jag kan därför icke känna mig övertygad om den nya uppfattningens riktighet. Vad Ödman har anfört såsom stöd för denna uppfattning, i form av iakttagelser utanför den nu avhandlade, begränsade trakten, är dock av sådan vikt, att de anförda lokala problemen ej kunna motivera något principiellt underkännande av densamma. För mig står frågan öppen.

När sålunda omfattande undersökningar icke ha givit resultat som tillåta bestämda slutsatser, kan man då ha någon utsikt att få frågan ytterligare belyst utan en orimlig arbetsinsats? Ett uppslag må påpekas.

Kurravaarakonglomeratets bollmaterial har, i vad angår blottningarna på Pahtosvaara och Valkeasiipivaara, på ett utmärkt sätt undersökts av Sundius (1915). Inför de förändrade frågeställningarna synes dock en förnyad granskning väl motiverad. Vidare har materialet längre åt NO, i Kurravaarabergen, aldrig blivit närmare beskrivet. En undersökning där kan tänkas ge upplysningar av värde. Skulle det visa sig, att de syenitporfyriska och keratofyriska bollarna träda tillbaka inom detta område, så skulle detta innebära ett stöd för Ödmans uppfattning. Kanske ännu viktigare är dock att få en så detaljerad kännedom om Kurravaarabergens geologi, att man kan bedöma, om den på Valkeasiipivaara konstaterade förkastningen fortsätter dit. Om denna förkastning (man vet icke om den är en överskjutning eller ej) har mera än lokal betydelse, så kan den knappast tänkas helt avtona inom ett par kilometers avstånd.

VAKKOSERIEN[1] OCH DJUPBERGARTERNA

Vakkoseriens inpassning i det stratigrafiska schemat har ju länge utgjort ett problem. Sedan jag (Geijer 1931) framförde den uppfattningen, att den utgör det distinkt yngsta sedimentära ledet inom områdets urberg och att bland djupbergarterna endast Linagranitens grupp är yngre, har ju, främst genom arbeten av Ödman (1939, 1957), åtskilligt nytt kommit i dagen rörande denna serie. Sålunda har Ödman lämnat avgörande bekräftelse på Linagranitens yngre ålder (1939). Vidare må framhållas uppfattningen att grönstenslavor uppträda konformt ovanpå Vakkosedimenten. Min föreställning hade varit den, att lavorna ifråga vore överskjutna över sedimenten.

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[1] Oavsett vad man anser sannolikt om Vakkosedimentens stratigrafiska ställning synes det lämpligt att för dem använda Ödmans beteckning »serie» i stället för min »formation».

Ödmans nu presenterade tolkning kan bäst återgivas genom direkt citat av hans sammanfattning (1957, s. 12): »Vakkoseriens relation till lapponium synes böra tolkas så, att den förra serien utgör en sedimentär facies i det lapponiska komplexet, lokalt utbildad i vissa, under sänkning varande bäcken. Sedimentens karaktär tyder på en snabb avsättning, ofta i och omkring mynningen av floder, som haft hög transportkapacitet och som sannolikt i branta lopp kommit från angränsande högländer. Vakkoserien överlagras konformt av lapponiska vulkaniter inom flera områden. N om Kiruna återigen ligger Vakkoserien konkordant på det sannolikt lapponiska Kurravaarakonglomeratet.»

Inom Vakkoseriens utbredningsområde är »lapponium i övrigt» representerat endast av Pajalaserien. Jag skall därför här bibehålla denna sistnämnda benämning och undvika termen lapponium, som ju enligt Ödman bör omfatta båda serierna.

Till den nyss citerade sammanfattningen må följande reflexioner knytas. Vakkoseriens utbredning har sannolikt varit ganska begränsad, men det synes föga troligt att avsättningen skulle ha ägt rum i flera skilda bäcken. Sedimenten börja alltid — i den mån bottnen är känd — med helt lokalt material, men deras huvudmassa är, i alla områden där man har anledning räkna med att lagerföljden är någorlunda fullständigt bevarad, en kvartsrik sandavlagring av i stort sett likformig karaktär. Någon grund att av sedimentens natur draga sådana paleogeografiska slutsatser, som göras i den citerade sammanfattningen, synes därför knappast föreligga.

När Ödman betecknar de Vakkosedimenten överlagrande grönstenarna som »lapponiska vulkaniter» måste detta naturligtvis uppfattas såsom avseende »vulkaniter av samma art som i Pajalaserien». Dylika, här till stor del såsom grönskiffrar föreliggande vulkaniter äro emellertid sådana vanliga företeelser att likheten, även om den bör noteras, dock icke innebär något bevis i åldersfrågan. Även enligt Ödmans uppfattning skulle ju också en lång sedimentationsperiod skilja dessa vulkaniter från Pajalaseriens; någon stratigrafisk identifiering kan sålunda ej vara avsedd.

Om nu Kurravaarakonglomeratet hänföres till Pajalaserien såsom en lokal avslutande bildning, och detsamma i Kurravaarabergen överlagras av Vakkoserien, så blir ju i alla händelser den senare ett klart yngre element än Pajalaserien. Fråga är då — hur mycket yngre? Har något geologiskt skeende av väsentlig betydelse ägt rum under tiden mellan de båda seriernas uppbyggande? Ödman menar, att så icke har varit fallet. Enligt den uppfattning, som jag tidigare (Geijer 1931) har framfört, skulle däremot de djupbergarter, som jag betecknat som den »äldre gruppen» (huvudsakligen serien syenit — pertitgrait) till tiden falla emellan. De olika uppfattningarna te sig således schematiskt ålunda:

Ödman 1957		Alternativt schema
Syenit, pertitgranit, Linagranit		Linagranit
Lapponium	Vakkoserien	Vakkoserien
	Pajalaserien	Syenit, pertitgranit
		Pajalaserien

Uti mitt alternativ är den ändringen gjord gentemot stratigrafien av år 1931, tt Pajalaserien nu, på grund av de senaste årens forskningar (Eriksson 1954, Ödman 1957) framträder såsom en självständig enhet och därmed ej blott den, tan också djupbergartsgruppen syenit-pertitgranit, har flyttats upp till en se- are åldersgrupp. Även för djupbergarternas tolkning är denna förändring be- ydelsefull. Tidigare (Geijer 1931) har jag fäst mycket avseende vid de likhe- er såväl i den allmänna kemiska karaktären som i vissa karakteristiska detaljer, åsom uppträdandet av rombfältspater, som föreligga emellan denna djupberg- rtsgrupp och de järnmalmsförande, förmodat svioniska porfyrerna. Om man u måste räkna med, att Pajalaserien är väsentligt yngre än dessa sistnämnda, å inskjutes emellan de båda nyssnämnda enheterna denna series basiska vulka- iter (och avsevärda tidrymder). Följaktligen faller då det resonemang, som ag har fört, angående ett visst magmatiskt sammanhang mellan porfyrerna och en nämnda djupbergartsgruppen.

Ödman tänker sig nu den förklaringen av de berörda likheterna, att djup- ergartsgruppen ifråga har uppkommit genom palingenetisk uppsmältning av vioniska vulkaniter. Dylika antaganden ha i svensk urbergsgeologi flera gånger ramkastats med den största lättvindighet. I det nu föreliggande fallet däremot innas obestridligen sakliga skäl för en sådan tolkning, under förutsättning av e antagna åldersförhållandena. Det får dock ej förglömmas, att den kemiska enomsnittssammansättningen på de båda eruptivgrupperna — porfyrerna och jupbergarterna — torde vara ganska olika. Saken är därför ingalunda enkel.

Vad som nu, liksom tidigare, synes mig tala för de ovan i »alternativt sche- na» angivna relationerna mellan Vakkoserien och de olika djuperuptiven är els den mycket omdiskuterade konglomeratboll av albitgranit vid Poketinjärvi, om talar för att Vakkoserien är yngre än pertitgraniten, dels också det förhål- ndet, att skillnaden såväl i kemiskt-petrografisk karaktär som i geologiskt upp- ädande emellan å ena sidan gruppen syenit-pertitgranit, å den andra Linagra- it, äro så stora, att deras sammanförande till *en* intrusionsepok förefaller osan- olikt.

Ödman betvivlar, att förekomsten av albitgranit såsom boll uti Vakkoseriens onglomerat vid Poketinjärvi får tillmätas något bevisvärde i detta samman- ang. Naturligtvis är den icke avgörande. Bergartens likhet, ej blott kemiskt- ineralogiskt utan också strukturellt, med sådan albitgranit som förekommer som randfacies på pertitgranitmassiv, är dock högeligen påfallande. Andra anitbollar skola visa granofyrstruktur; Ödman framhåller att de kunna vara vioniska. Detta är riktigt, men sådan struktur är inom området ej *känd* från andra djupbergarter än pertitgranit och den närstående kvartssyeniten. Sann likast synes därför vara, att albitgranitbollen ifråga härrör från randzonen p ett massiv av pertitgranit, men mera än ett indicium är den icke.

Den grupp av djupbergarter, vars vanligaste led jag har betecknat som pl gioklas-pertitsyenit, kvarts-pertitsyenit och pertitgranit, bildar en väl karakt riserad petrografisk provins, vars olika led äro förbundna genom övergångar. sitt geologiska uppträdande utmärkes gruppen därav att någon migmatitbild ning eller över huvud taget någon mera framträdande intrusiv uppblandnin med sidstenen ingenstädes är känd. Porfyriska gränsformer med granofyris grundmassa ha iakttagits på flera ställen. Pegmatiter saknas — möjligen ä dock ett par gångar i Masugnsbytrakten (Isovaara) att ställa i samband me där uppträdande pertitgranit.

Linagraniten (i petrografisk mening) och de densamma även petrografis närstående former som likna den i sitt geologiska uppträdande, äro med si kombination av måttligt pertitisk mikroklin och fri plagioklas, ävensom nästa undantagslöst högre anortithalt, på det hela taget distinkt skilda från den fö utnämnda gruppens graniter. Lika mycket gäller detta om deras geologisk uppträdande, med migmatitisering, massuppträdande av pegmatitgångar i s dostenen, o. s. v. Kontrasten framträder särskilt starkt vid Masugnsbyn (Geij 1929), där de till Tarrilainens Linagranit anslutna pegmatiterna nå fram ti endast ca 600 m från pertitgraniten med dess skarpa kontaktlinje och albi granitiska, delvis granofyriska randzon.

När Ödman, trots dessa för honom väl bekanta förhållanden, sammanställ de båda ifrågavarande grupperna av djupbergarter, så grundar sig detta ha ställningstagande främst på den uppfattningen, att i en del förekomster en öve gång föreligger mellan pertitgranit och Linagranit. Obestridligen förekomm former, vilkas klassificerande under fältarbetet kan ställa sig svårt. Sålunda h Ödman visat mig stuffer av Kompelusvaaragranit som avgjort likna pertitgr niten, men den mikroskopiska bilden bekräftar ej denna bestämning. Det beklagligt, att problemet pertitgranit — Linagranit ej har kunnat upptagas t en specialbehandling. Vad man nu har att hålla sig till, är en deklarerad up fattning men icke de observationer på vilka den grundar sig, om ock kart ger vissa anvisningar. Frågan har betydelse vida utöver de lokala geologis förhållandena, ty om dessa till kemisk karaktär och geologiskt uppträdande olika djupbergartsgrupper skulle vara att jämställa så nära, som Ödman a ser, så rubbas därmed grunderna för flera nu, särskilt inom urbergsgeologie såsom välgrundade arbetshypoteser betraktade åskådningar.

Olikheten i geologiskt uppträdande vill Ödman emellertid förklara på sätt, att de migmatitiserande graniterna tillhöra geosynklinalområden men övriga äro intruderade under andra förhållanden. Om man försöker att i pra tiken genomföra denna uppdelning synes resultatet dock bliva en mycket ko plicerad och föga sannolik bild.

När man söker bedöma Vakkoseriens plats i det stratigrafiska schemat b tydligen den avgörande faktorn, såsom så ofta i geologien och ej minst när d gäller urbergsstratigrafiska spörsmål, den ofrånkomligen subjektiva värdesä

ingen av indiciebevis. Jag vill ingalunda bestrida, att Ödman kan åberopa vä-
ande skäl för sin ståndpunkt i frågan, men jag vill dock hålla före, att den här
åsom alternativ presenterade ordningsföljden innebär en bild som väl mot-
varar de kända fakta och i vissa avseenden ter sig mera sannolik.

Problemet om Vakkoseriens relativa ålder spänner över ett så pass stort om-
åde, att det kan synas utsiktslöst att genom vidare undersökningar inom rim-
ig omfattning komma längre i saken än vad den nu avslutade undersökningen
ar fört den. Dock vill jag peka på ett område, där en även ur andra synpunk-
er högst önskvärd detaljundersökning möjligen kan ge upplysningar av värde
ckså i denna fråga. Jag syftar på Kurravaarabergen. För Ödmans uppfattning
v Vakkoseriens ställning är det, såsom framgår av det ovan återgivna citatet,
tav avgörande betydelse, att denna serie anses konformt överlagra Kurravaa-
akonglomeratet (och därmed Pajalaserien) därstädes. Men en sådan undersök-
ing måste göras ytterst detaljerad, ej minst med tanke på möjlig förekomst av
naskerade överskjutningar. Såsom redan har påpekats är det, om förkastning-
n på Valkeasiipivaara vore av väsentliga mått, högst sannolikt att densamma
ortsätter mot NO i Kurravaarabergen. Med tanke på hur besvärligt det har
arit att på platsen *bevisa* en dylik förkastning på Valkeasiipivaara, så är det
äl också troligt, att en eventuell fortsättning under Vakkoserien i Kurravaara-
ergen kan vara lika svår att konstatera. Framförallt synes det emellertid svår-
örenligt, att Kurravaarakonglomeratets övre yta å Valkeasiipivaara skulle vara
tt förkastningsplan, men i Kurravaarabergen basen för en normal, konform
verlagring av Vakkosediment.

SNAVVA-SJÖFALLSSERIEN

Genom Ödmans beskrivning framstår nu denna förmodat svioniska sediment-
erie i en intressant belysning, som inbjuder till några kompletterande reflexio-
er. Av det nya, som nu har tillkommit utöver tidigare, preliminärt meddelade
ppgifter, fäster man sig särskilt vid mäktigheten, som i norra delen uppskattas
ill ca 10 000 m.

För en del år sedan framhöll jag[1], att en avlagring av Snavva-Sjöfallsseriens
atur måste härröra från en landyta av väsentligen granitiska bergarter. Det är
v Ödmans data numera tydligt, att det rör sig om en sedimentation av enorma
vantiteter detritusprodukter, av kornstorleken sand, härrörande från ett om-
åde där graniter (eller granitiska gnejser) ha undergått mekanisk vittring och
tark erosion. Den geosynklinalbildning, som enligt Ödman föreligger här, har
ålunda — om dess datering såsom svionisk är riktig — fått sin väldiga sedi-
entutfyllning från en pre-svionisk landyta, sannolikt med stark relief.

De måhända något spekulativa utblickar, som beskrivningen av Snavva-Sjö-
allsserien sålunda inbjuder till, må i sin mån illustrera, vilka intressanta geo-
ogiska perspektiv som öppnats genom Ödmans och hans medarbetares under-
ökning av Norrbottens läns urberg.

Citerat (med instämmanden) av Asklund (G. F. F. 66: 317, 75: 316) och S. Gavelin (ibid.,
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från

SVENSKA FÖRENINGEN FÖR LERFORSKNING

Reports from The Swedish Society for Clay Research

Nr 10

December 1958

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Föreningens ändamål är att främja intresset för vetenskaplig utforskning av lerornas egenskaper och att sammanföra för detta syfte intresserade personer till föredrag och diskussioner angående gemensamma problem.

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Vårmötet 1958

Svenska föreningens för lerforskning vårmöte hölls den 5 maj vid Kungl. Tekniska Högskolan i Stockholm.

Ordföranden öppnade mötet med följande anförande:

Sedan föreningen sist samlades har en av våra ledamöter lämnat oss.

Den 29 januari avled professor Helge Götrik Backlund i Uppsala i en ålder av 79 år.

Backlund var född den 3 sept. 1878 i Dorpat.

Efter studier i St. Petersburg, där hans far hade blivit direktör för tsarens observatorium i Pulkova, blev han kustos, senare chefskustos, vid ryska vetenskapsakademiens geologiska museum, en befattning som han innehade 1902—1917.

Under denna period var han även 1912—13 argentinsk statsgeolog.

När ryska revolutionen bröt ut 1917, var han i Sibirien, och han gav en gång för c:a

25 år sedan vid ett »Nachspiel» i Geologiska Sektionen, en mycket målande bild över den farofyllda och äventyrliga hemfärden.

Han överflyttade 1918 till Åbo Akademi, där han blev professor i geologi och mineralogi.

Slutligen blev han professor i geologi med mineralogi och petrografi vid Uppsala Universitet 1924 som efterträdare till professor A. G. Högbom. Han pensionerades 1943.

Backlund var mycket vittberest och hans stora intresse var ju bergskedjebildningar av skilda åldrar, särskilt i våra nordligare trakter. Om svenska urberget, om fjällkedjan samt frågan om graniternas natur och bildningssätt samt mycket annat, handla de över 100 skrifter där han framlagt sina rön.

Som akademisk lärare var Backlund mycket fordrande, men hans undervisning var mycket grundlig och han fordrade också mycket av sig själv. Under min tid i Uppsala kunde man ta sig hem över St. Eriks Torg hur sent som helst, nog lyste det mestadels från fönstret i professorsrummet på »Geologen».

Som erkänsla för hans stora förtjänster inom den geologiska forskningen fick han 1943 Gustaf Steinmann-medaljen och samma år utgav Geologische Rundschau en festskrift för att hylla honom.

För mig personligen kommer han alltid att stå som en vördad och aktad lärofader. Jag lyser frid över hans minne.

Till ledamöter i valnämnden valdes civiling. R. Lundström, sammankallande, civiling. L. Andersson och civiling. G. Lindskog.

Professor I. Th. Rosenqvist, Oslo, höll därefter ett föredrag med titeln: Nye undersøkelser over kohesjon og plastisitet i leire. I anledning av föredraget yttrade sig hrr Assarsson, Järnefors, Kallstenius och föredragshållaren. Ett autoreferat av föredraget följer nedan.

Fil. lic. L. Arnborg, Uppsala, höll ett föredrag med titeln: Vattenregleringarnas inverkan på erosionsformer och fluviala processer inom nedre Ångermanälven. Grodmansundersökningar i vetenskapens tjänst.

Tekn. lic. S. T. Lundin, Stockholm, höll ett föredrag med titeln: Experimentella kinetiska data för mullitens utbildning vid några kaoliner. Ett autoreferat av föredraget publiceras i detta häfte.

Geolog S. Fredén, Stockholm, höll ett föredrag med titeln: Försök med elektroosmotisk avvattning av lera. I den efterföljande diskussionen yttrade sig hrr Hagerman, Jakobson och föredragshållaren.

Efter gemensam lunch på studentkårens restaurang visades de nya laboratorierna vid Sveriges Geologiska Undersökning av laborator G. Assarsson och fil. lic. B. Järnefors.

Sammanträdet hade samlat ett 40-tal deltagare.

Nya medlemmar

Korporativ medlem

Yxhults Stenhuggeri Aktiebolag, Hällabrottet

Medlemmar

Heien-Larssen, Kirsten, Civiling., Sveriges Geol. Unders., Stockholm 50
Hellgren, A., Byråing., Stockholms Stads Gatukontor, Fack, Stockholm 8
Kihlstedt, P. G., Professor, Molinvägen 13, Bromma
Osterman, Justus, Övering., Statens geotekn. inst., Narvavägen 25, Stockholm Ö
Pusch, Roland, Civiling., (Hamnförvaltningen, Norrköping), Ljuragat. 81, Norrköping
Regnell, Ulla, Fil. lic., Min.-geol. inst., Sölvegat. 13, Lund
Åkerman, Alf, Civiling., Reymersholms Gamla Industri AB, Hälsingborg

Remarks to the Mechanical Properties of Soil Water Systems[1]

By

IVAN TH. ROSENQVIST

Norwegian Geotechnical Institute

With 9 figures in the text

General Review

The mechanical properties of the so-called "cohesive soils" have been dealt with as a subject of scientific research for more than thirty years. Several genetically different soils belong to the group of cohesive soils.

By sedimented clays we understand soils formed by sedimentation of clay forming minerals in fresh or salt water. Subsequent to the consolidation no important chemical changes are supposed to have taken place in the mineral phase. Although related to residual clays and some other weathered soils, the sedimented clays form an easily distinguishable group.

In 1923 ASSAR HADDING proved by X-ray analyses that clays mainly had a crystalline nature. (The minerals known to us today as illites were by him regarded as muscovite.)

In 1925 KARL TERZAGHI published his famous book "Erdbaumechanik auf Bodenphysikalischer Grundlage". Here we may find a remarkably modern discussion concerning the structure and bonds in cohesive soils. TERZAGHI drew the attention to the adhesion between minerals. what he called "Null-reibung" and held that the cohesion in clays was due to adhesion between adjacent minerals. He suggested that the minerals stick to each other at the points of contact with forces sufficiently strong for the building up of a honeycomb structure, so that comparatively large amounts of water may be enclosed within voids built up of aggregates of minerals glued to each other by the adhesion forces. Thus, each cell in the honeycomb structure was supposed to be made up of numerous single mineral grains (Fig. 1). TERZAGHI disagreed with the general opinion of the cohesion at that time, as due to some undefined action of a hypothetic amourpheous clay substance. V. M. GOLDSCHMIDT was mostly known because of his geological and geochemical work. He also published 8 papers concerning clays. He was mainly interested in the clays as mineralogical raw materials, but dealt with their mechanical properties too. He performed series, of experiments with mixtures of clay minerals with various liquids as water, benzene, carbontetrachloride, liquid sulphur dioxide, and ammonia.

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[1] Lecture given in The Swedish Society for Clay Research on May 5th 1958.

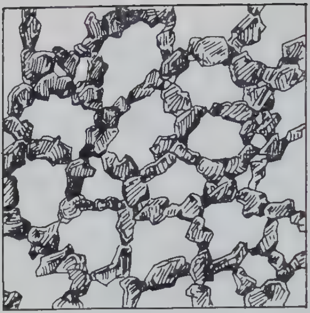

Fig. 1. The Terzaghi-Casagrande concept of honey-comb structure, redrawn from TERZAGHI: Erdbau-mechanik auf bodenphysikalischer Grundlage.

In this way he discovered that the mixtures had plastic properties, provided the liquids had a typical polar character, whereas if the liquid involved was non-polar, as for instance carbontetrachloride, he obtained mixtures without plasticity, analogous to what was found in mixtures of silt and water. He concluded that the clay properties (mainly the plasticity) were dependent both upon the crystal chemistry of the mineral phase and the atomic structure of the liquid phase.

In 1926 this view was presented in its conclusive form. GOLDSCHMIDT expressed here the opinion that the clay properties were due to crystalline minerals surrounded by a film of adsorbed water molecules and that the water molecules stick to each other and to the minerals because of their dipole moment. In his published university lectures, he expressed the opinion that the flaky minerals in the high sensitive clays are arranged in instable cardhouse structures. This view is, therefore, somewhat different from the honeycomb structure of TERZAGHI, as GOLDSCHMIDT held it that the surplus water was enclosed in the space between a few mineral flakes leaning upon each other. He thought that the difference between clays of high and low sensitivity was due to a denser arrangement of the minerals in the clays of low sensitivity.

In 1932 ARTHUR CASAGRANDE presented a theory of honeycomb structure in sensitive soils, very similar to that of KARL TERZAGHI.

In 1946 the present author showed that there could be no important difference in the mineral arrangement of normally consolidated marine clays. With a given grain distribution, the water content was independent upon whether the clays have high or low sensitivity. It was shown that the sensitivity in the quick clays was connected with the colloid chemistry of the system. In case of heavily overconsolidated clays of low sensitivity, SKEMPTON and NORTHY in 1952 expressed the opinion that their low sensitivity was due to a collapse of all the structures during the consolidation.

In 1953 WILLIAM LAMBE presented his paper "Concerning the structure in inorganic soils". He strongly held colloidal chemical view points and showed schematic pictures of the mineral arrangements in clays. For the undisturbed marine clays an open structure similar to GOLDSCHMIDT's cardhouse structure is shown, whereas in fresh water sediments the structure was thought somewha

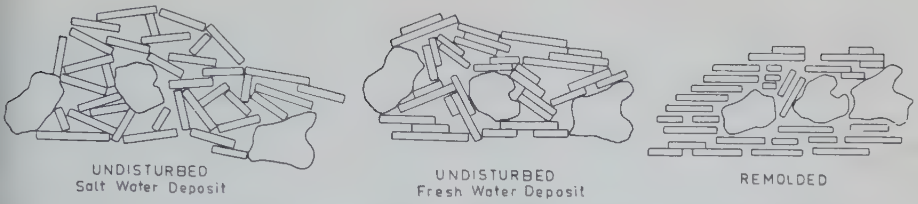

Fig. 2. The Goldschmidt-Lambe concept of cardhouse structure, redrawnfrom T. William Lambe: The structure of inorganic soils.

denser and in the remoulded clays was supposed to have a high degree of parallelism and short range order between the flakes (Fig. 2).

A very similar view on the structure of the clays was held by the present author in 1955 and by Bjerrum and Rosenqvist in 1956. Even though indirect methods have given us very good reason to suppose that the mineral arrangement in the undisturbed sedimented clay is of the type suggested by Lambe, we have not until recently had sufficiently good means really to investigate this point directly. Using the special technique described in the 1955 paper, the present author could present a fairly good picture of the mineral arrangement based on optical microscopy, but the pictures were too fluffy to be sufficiently convincing.

In 1957 T. K. Tan presented a schematic picture (Fig. 3) of clay mineral network dominated by contacts between a corner of one mineral and the plane of another.

As will be shown later in this paper, we have now by means of electron microscopy been able to prove that the mineral arrangement in the undisturbed marine clays really corresponds to the cardhouse structure suggested by Goldschmidt and later by Lambe, and in fact exactly corresponds to the imaginative drawing of Tan. The fact that this structure has been proved, suggests in itself that concept of friction and cohesion in clays should be taken up to new consideration. These two terms have been used ever since the days of Coulomb in the end of the 18th century.

Although the definition has been rather vague, today we speak of "true friction" and "true cohesion" in Jul. Hvorslev's sence of the words, using the terms of effective stresses. The Coulomb equation in its present form runs:

$$S = (\sigma - u) \cdot \mathrm{tg}\varphi' + c'$$

σ = total stress
φ' = "true" angle of friction
u = pore water pressure
c' = "true" cohesion

With most soils, independent upon whether they are designated frictional soils or cohesional soils, we find that the energy of deformation at failure is different in the natural state and in the remoulded state, as long as the water content is kept constant. This is the case even when the remoulded soils are kept for a long time after the deformation. Of greater immediate importance

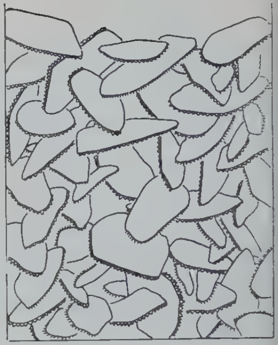

Fig. 3. Schematic picture of clay network. (T. K. Tan, 1957).

than the energy of deformation by failure is, however, the shear strength (drained or undrained). This value is normally lower in the remoulded than in the undisturbed state.

As it is much easier to deal with a completely remoulded soil than with a completely undisturbed soil, the majority of the studies has dealt with the properties in the remoulded state. For instance, the liquid limit refers to the water content at a very low value of the remoulded shear strength. The vulgar concept of the shear strength as made up of two terms, viz. the friction and the cohesion, gives us a very simplified picture of the complicated factors co-operating in what we call "the shear strength of a soil". The friction term is undoubtedly made up of different parts. We have the so-called "macro-dilatancy", which everybody can visualize. This part of the friction is caused by the lifting of one mineral grain on one side of the shear plane above another grain on the other side of the shear plane when the shear movement takes place. A so-called "micro-dilatancy" is of corresponding nature. In this case we understand the resistance towards shear due to the roughnesses in one mineral particle which must be lifted up and pass along the roughnesses of another mineral particle. It is obvious that both these terms will be proportional to the effective normal stress in the shear plane. Further, it is obvious that the resistance to movement in such systems will depend upon the velocity of deformation and the viscosity of the liquid phase of the voids as a deformation involves a transport of the liquid phase. However, we have at least one additional term which gives shear resistance as a function of the normal stress in the shear plane. This term we have called "the non-dilatant friction term". Here we understand the resistance to shear due to mass forces between the atoms in the one mineral and the atoms in the other mineral. Such forces will exist independent upon whether the minerals behave as completely elastic bodies or as unelastic, plastic bodies. In both cases the area of contact will increase and the distance between the atoms in two neighbouring minerals will decrease by increasing normal pressure. Due to these decreasing distances, some of the attractive forces will increase in the same amount. Even the dilatant terms are, in fact, functions of the non-dilatant terms. This friction term is directly related to the sliding friction between sliding surfaces tgφ. In grain aggregates the apparent friction tgφ is related to tgψ and the angle between the contact planes and the shear plane β and the porosity n

$$\mathrm{tg}\varphi = \mathrm{tg}\psi \frac{1 + \mathrm{tg}\beta}{1 - \mathrm{tg}^2\beta} \mathrm{tg}\psi \frac{\pi}{2} f(n)$$

F. P. Bowden, together with several coworkers, has carried out fundamental research concerning the nature of the non-dilatant friction (see Bowden, F. P. and Tabor, D.: The Friction and Lubrication of Solids. Oxford University Press, 1954). From his publications we may draw several important conclusions: Primarily that the area of actual contact between two solid bodies is very low, e.g. under normal loads the area of contact between two steel surfaces will be of the order 1 100 000 of the apparent area of contact, as the real area of contact is nearly independent of the total area and only dependent upon the load. The real area of contact is only to a small extent influenced by the roughness and shape of the metal surfaces. The real area of contact may as an approximation be expressed by the following equation

$$A = \frac{W}{Pm}$$

W means the total load and Pm the yield value of the material. As the non-dilatant friction is regarded as due to the adhesion in the area of contact, we may as an approximation state that

$$F = A \cdot s$$

F means the friction and s the shear strength of the junction. Thus we obtain a close connection between friction and adhesion. The friction represents the shear strength and the adhesion the tensile strength of the bonds in the contact area. The difference in the non-dilatant friction for various solid substances is mainly due to variations in their mechanical properties, as the contact area as well as the strength of the bonds are determined by these properties. Materials which give a high friction will also give a strong adhesion. The reason why we do not observe this adhesion is mainly due to the elastic stresses occurring in and around the contact areas. These stresses will be released when the load is taken away, and may be sufficiently strong to break the bonds of adhesion. When these stresses could be avoided by re-crystallization or by the ductility in the junctions, the adhesion will be observed.

It seems as if each of the three different friction terms mentioned will depend upon specific angles of friction and specific deformation at failure. The deformation of failure decreases in the order from “macro-dilatant” through “micro-dilatant” to “non-dilatant friction”. The deformation at failure will thus determine which friction term we have to consider when the shear strength value is measured.

Turning to the cohesion term in cohesive soils, it has been pointed out

(Fourth Intern. Conf., Proc. No. 3, p. 257) that the liquid limit of clays mainly depends upon three factors:

(1) The amount and nature of the minerals.
(2) The degree of electro-chemical saturation.
(3) The polarizability of the adsorbed ions.

There is an important difference between the montmorillonitic clays and the illite clays, in respect to the influence of the adsorbed cations. Thus lithium and sodium montmorillonites have abnormally high swelling power, because these cations cannot keep the single sheats of the lattice together. With the larger alkali ions, viz. potassium, rubidium and caesium, the internal swelling property is absent. This was shown by X-ray-methods by R. S. Dyall and S. B. Hendrics (Soil Science Society of America, Vol. XVI, 1952, pp. 44—49). Montmorillonites which have adsorbed the larger cations thus behave analogous to the illites, and give a regular increase in the liquid limit by increasing polarizability of the adsorbed cations.

Already Karl Terzaghi had noticed the influence of the different electrolytes upon the consistence of clays. In fact even the pre-historic ceramists seem to have known the influence of soda ash upon the consistence of clay when they manufactured their pottery. This influence is related to the degree of electro-chemical saturation. By the leaching experiments, it has been shown that the electrical charge of the mineral grains may have an important increase during leaching due to dissociation of the adsorbed cations from the clay mineral rests. Correspondingly the negative charge of the mineral may increase when certain anions are adsorbed as for instance a carbonate ion from soda ash or other anions as phosphates and silicates. Salts of such anions are used as dispergents in most soil laboratories. The effect is due to an increase in the repulsive forces between the highly negative charged minerals because of the anions adsorbed. This will change the mechanical properties of a clay-water mixture at a given water content. We have shown (op. cit. 55 p. 77) that the liquid limit of a Norwegian illite clay may decrease from 42 to 29 when small amounts of $Na_4P_2O_7$ is added. With addition of such salts, we may influence the shear strength by a given water content in a similar way as by leaching out the normal salt content; we may even simulate the formation of quick clays. Several papers by P. A. Rehbinder and coworkers published by SSSR Academy Nauk in the years 1940—1957 deal with the rheological properties of clay pastes as colloidal chemical functions. These papers most excellently point out the importance of the Van der Waal's forces in the coagulated clay systems. The modern Sovjet clay science is to a very high degree influenced by the viewpoints of Rehbinder. In the West the colloidal chemical view has gradually penetrated during the later years.

In addition to the factors acting in the remoulded state (in pastes), the shear strength of a consolidated sedimented clay is a function of

(4) The water content.
(5) The stress history.
(6) Diagenetic cementation.

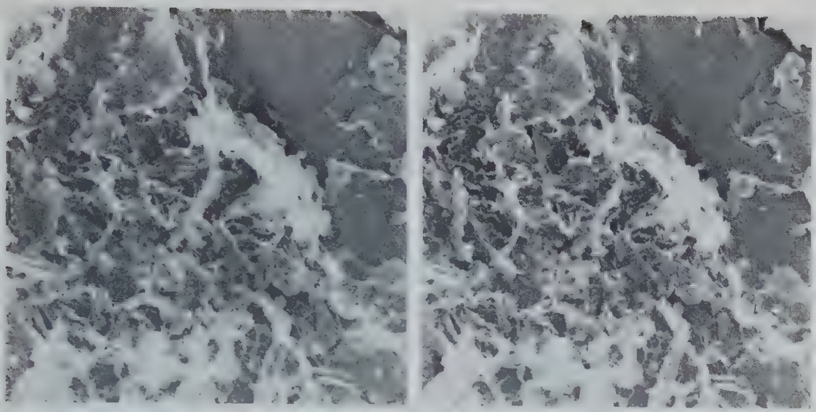

Fig. 4. Stereoscopic picture of the vertical section in undisturbed Oslo clay. 8 000 ×.

To take the last point first, many soils are found where amorphous or crystalline nineral substances have precipitated between the minerals thus forming a con- inuous skeleton of minerals. It is obvious that a shear through such a soil will lepend upon a failure in the cementing substance on the original minerals. (See N. J. DENISOV and P. A. REHBINDER: On Colloid-chemical Nature of Cohesion in Argillaceous Rocks, Doklad of Acad. Nauk SSSR, Vol. LIV, p. 519 -522.) Even though it is impossible at present to calculate quantitatively he real strength of a mineral crystal from the lattice forces of the substance, t is in principle easy to understand why a mineral crystal has shear strength. The cementation in addition to the effect of stress history is involved in the concept "structural cohesion" as mentioned by DENISOV and RELTOV (Fourth Int. Conf. IA 29). Disregarding the cementation which is unimportant in geologically young sedimented clays (i.e. Würm-post Würm Clays of Scandinavia), n such cases we have to deal with the action of friction and cohesion in a liscontinuous system where the different minerals may be separated by a lim- ted layer of adsorbed water between the grains, or where the grains are in physical contact.

The GOLDSCHMIDT-LAMBE theory of the mineral arrangement in undisturbed clays needed for its confirmation a technique not developed at that time. Using nodern electron microscopy methods pictures as seen in Figs. 4 and 5 are obtained. As will be seen the arrangement tallies with the schematic picture in LAMBE's paper and to an astonishing degree with the hypothetic scheme of Tan (Fig. 3). It is our opinion that the specimen really represents the mineral ar- angement in an undisturbed clay. The specimen was prepared by quick free- ing of a 2 cm thick plate of undisturbed blue marine Oslo-clay, which was mmersed in liquid air. Subsequently the frozen specimen was dried in vacuum t a pressure of about 10^{-3} mm Hg. The freezing in liquid air involved a very light volume increase (3 %), whereas the drying took place without any neasurable change in dimensions. The dried plate was broken mechanically

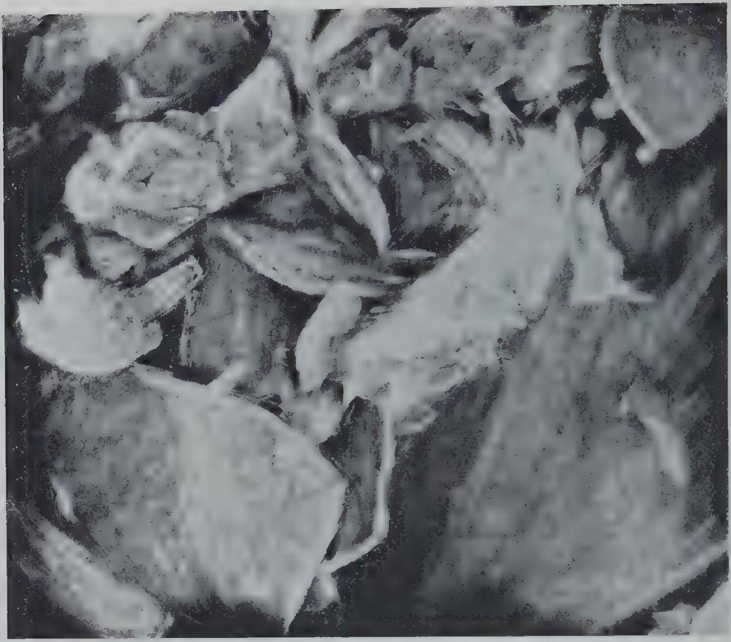

Fig. 5. Mineral arrangement in blue Oslo clay, (perspective).
ca. 25 000 ×.

and the central part of the (vertical) surface thus obtained was used for th carbon replica, which was photographed in the electron-microscope.

The technique used for the preparation of the carbon replica is a slight modificatio of the technique published by COMER AND TURLEY. Because of the roughness of th surface of the freeze-dried and broken clay specimens, these were rotated (ca. 40 rpm) during the evaporation of the carbon. The evaporation was performed at a angle of about 45° in order to get a relatively uniform film thickness. On top of th carbon film a thick (0.1—0.2 μ) aluminium film was evaporated. This stage was intro duced to avoid the influence of the polystyrene (applied hot on the specimen) on th dissolution of the clay in hydrofluoric acid, as this type of clay, contrary to most othe types, is difficult to dissolve when the polystyrene is applied directly on to the carbo film. Before dissolving the clay, most of it is washed off with water. After the treatmen in hydrofluoric acid, the replica is washed and mounted in the usual way.

The minerals seen on the photographs are mainly hydrous mica (illite) an 2 larger feldspar grains at a slightly inclined angle to each other. An importan point seen in the stereopictures is the very open mineral arrangement dominate by contacts between corners and planes. Until now we have examined mo than 20 clays in this mineral and have found the same arrangement in a marine clays. Thus, the "corner plane-cardhouse" arrangement is very well con firmed.

Polarizability of the Adsorbed Cations

In an earlier paper, Publication No. 9, from Norwegian Geotechnical Institute, pp. 111—112, it was stated that the shear strength of certain clays substituted with different cations had a relation to the calculated polarizability of the adsorbed cations. It was mentioned that, provided that Van der Waal's forces acted between the adsorbed cations on one mineral and the lattice field of an adjacent mineral, the forces should be proportional to the first power of the polarizability. Provided that the forces took place between the same type of ions on the two minerals, the attraction should be proportional to the second power of the polarizability of the ions. In case of illitic clays substituted with alkali cations, the first power relation was found. This is also to be inferred from the Goldschmidt-Lambe cardhouse arrangement, where edges of one mineral are in contact with the planes of another mineral, provided the conditions for adsorption are different along the edges and along the planes. Later experiments published at the Fourth International Conference confirm this concept. In discussions with colleagues it has verbally been raised the question whether the polarizability or merely the size of the cations is of importance. This question seems to be elucidated from the following experiment:

In a series of test tubes, the same amount of a diluted clay slurry was mixed with the same amount of half-normal solutions of the chlorides of the following cations: lithium, potassium, caesium, aniline, cyclohexylamine. The final sedimented volume after 6 weeks is seen from the picture (Fig. 6). In this case we

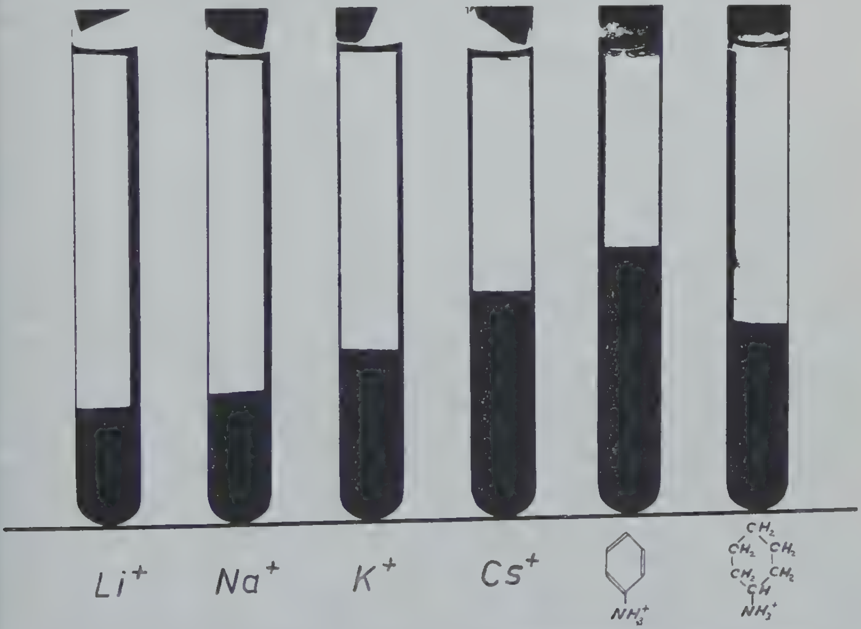

Fig. 6. The final sediment volume of the same amount of clay minerals sedimented in water containing equimolar concentrations of chlorides of various monovalent cations.

have the aniline and the cyclohexylamine of very similar configuration. Due to the conjugated double bonds in the aniline ions, however, this ion is much more polarizable than the cyclohexylamine. The volume of the aniline clay seems to be about 50 % larger than the volume of the cyclohexylamine clays. This shows that the bonds between the minerals substituted by the cyclohexylamine are weaker than those substituted by the aniline. Consequently, a denser structure is necessary to carry the weight of the minerals in the cyclohexylamine clay.

If we suppose that the clay sediments in the test tubes were consolidated to the same water content, it seems obvious that the lithium clay would exhibit a lower shear strength than the rest of the clays, and that the aniline clay would exhibit the highest shear strength value. In such a case, the arrangement of the mineral skeleton and the water phase could not be very different in the single sample, the main difference being that the adsorbed cations on the surface of the minerals have very different polarizabilities, thus creating variations in the attractive force between the minerals. This again means that the adhesion between two neighbouring minerals with the same contact area is greatest in the aniline clay and lowest in the lithium clay.

The Water Phase

The fact that the water phase nearest to the clay minerals has an intrinsic energy similar to that of ice, makes it probable that the physical state is very near that of a solid body. The concept "solid body" is, however, poorly defined and may be applied to materials varying from soft greasy crystals, to diamonds and pure grown metal monocrystals and other materials with tensile strengths a hundred times higher than that found in ordinary ice. From this, a mere knowledge of the free energy of the water phase surrounding the clay minerals will, in fact, tell us nothing about the real shear of tensile strength in this phase. However, we have many reasons to suppose that the physical state of some part of the water phase in clays may differ considerably from that of ordinary water.

Much importance has been contributed to the water phase nearest to the clay minerals. By different authors this water phase has been supposed to glue or weld the minerals together, thus being responsible for the cohesion term of clays. The concept of a relatively thick bound water layer around the clay minerals have entered into the clay literature at a very early time and is still often encountered. Measurements of heat of swelling and the vapor pressure/temperature relations of a particular clay substituted by different cations proved, however, that the calculated thickness of the "crystalline water" corresponds to an ice layer of the order 10 Å thickness surrounding the minerals. It seems, however, as if there is a gradual decrease in the degree of the order, so that the influence of the minerals will act upon the water phase to a somewhat greater distance, say 25 Å but not much more. To follow up this point, we have determined from practically dry to about the plastic limit the vapor pressure temperature curves for a clay with a known surface at a variable hydratisaion over a long range of water contents. The values found confirm the exponential increase in free energy as a function of the distance from the mineral surface. Therefore, it must be appropriate to speak about a thin adsorbed diffuse water film. Innermost, the water, at least, is influenced by the mineral n such a way that the bonds correspond to those in a solid material (ice). It s a well-known fact that even when dried at 110°, the clays contain important mounts of hydrogen which will be given off by further heating. In case of llite clays, this water is supposed to be present in three different states:

(1) Firmly adsorbed water (icelike water).
(2) Water present as H_3O^+. } (lattice water)
(3) Water present as OH^-.

The presence of the first group of water is inferred from the fact that there s but a gradual change in the slope of the dehydration curve when the heating s continued above 100°. The presence of water in the state (2) and (3) is directly seen from the formula of the illites.

In order to investigate the mobility of the water in the different states, we have tried exchange reactions between the protium of the dried clay minerals and the deuterium of added heavy water. (Full description Geochemica Cosmochemica Acta. 1958.) The experiment was carried out in the following way: In each of a series of test tubes, 10 g clay powder, dried at 110°, was mixed with one gram of heavy water, and the tubes were immediately sealed off. The ubes were then kept for a given time and then opened and the water phase distilled at a temperature of 110°. Determination of light hydrogen in the heavy water would then directly give the amount of exchange between the free water phase and the water present in the pre-dried clay powder.

In another series of corresponding experiments, moist clay powder was mixed with a larger surplus of heavy water and immediately afterwards separated gain by means of vacuum filters. This procedure could be done in a time horter than one minute. It proved, however, that even such a short time was ot sufficiently short to give any idea as to the slope of the first exchange reacions. Even at a time of 53 seconds, we had complete exchange between the eavy water and an amount of water corresponding to that given off by the minerals by heating them at a temperature of 110°. Conventionally we call the ried residue of a soil heated to 110° C "The mineral phase", and the water xpelled up to this temperature is called "The water phase" despite the fact hat the liquid phase filling the voids in soils often contains non-volatile disolved substance in considerable amounts. Further the soil dried at 110° conains a considerable amount of hydrogen in one state or another.

The result of the different exchange reactions mentioned, was that the rotium of the "mineral phase" underwent exchange reactions with the deuerium of the water phase at different velocities. *One part of the hyrogen corresponding to about 13 % of the total hyrogen content after heating to 110° C, was completey exchanged with the surrounding water phase*

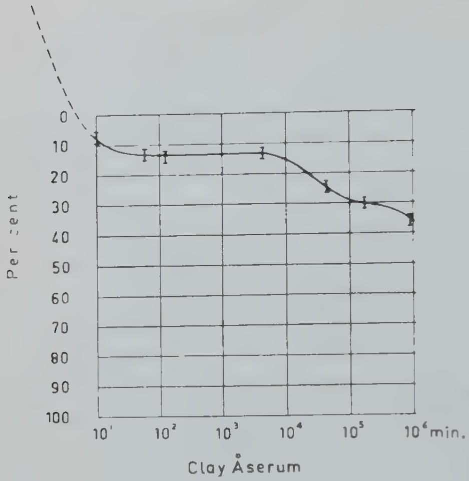

Fig. 7. Exchange of H/D in pe cent of H content, 100° C.

within a few minutes; another part corresponding t about 17 % of the hydrogen content at 110° C neede weeks before equilibrium with the surrounding wate phase was reached, and the third part correspondin to about 70 % of the hydrogen content had no reached equilibrium even after 610 days; most probably several years — or even centuries — are necessar before 100 % equilibrium is reached (Fig. 7). Eventually however, all hydrogen atoms of the clay minerals will interchange and be i equilibrium with the free pore water.

Thus, we have to conclude that the normal clays will have their wate present in different states. Some water is filling up the voids and may be presse off mechanically by moderate forces. Conventionally we call this water th "pore water". This includes the so-called "capillary water". There is no physical basis for a distinction between "free pore water" and "capillary water", bot terms describe mobile H_2O molecules in normal associations. The only difference is found in the hydrostatic pressure. Another part of the water cann be pressed out by stresses normally applied, but it will be expelled by moderat heating or drying in an atmosphere of low relative humidity. In addition t these two states of water which represent more or less normal water, we hav the three states of hydrogen mentioned above. It is, of course, convention where to draw the border lines between the different states. We prefer to mak a separate group of the water content which is given off and taken up betwee room temperature at 96 % humidity and 110° C at 0.6 % humidity. This valu is used because 0.6 % relative humidity roughly corresponds to the water content of normal laboratory air when heated to 110°. The water given off betwee these two limits we call the "hygroscopic" or "loosely adsorbed water". As see from the isotope exchange, there will, however, still be some water which do ot differ qualitatively but only by degrees from this hygroscopic water. We all it the "firmly adsorbed water". The rest of the hydrogen is then present as I_3O^+ and OH^- ions in the silicate lattice. These last states of hydrogen are enerally accepted to belong to the mineral structure proper. All these dif-erent states of water are necessary in order to make up the natural mineral' ater systems called clays.

The first water mentioned represents the pore liquid filling up the voids. This water is not considered as a part of the mineral phase, although it may be fluenced by forces from the mineral lattices. The loosely and firmly adsorbed ater may or may not be considered a part of the mineral phase. The study of e plasticity and shear strength of clay suggests, however, that it is natural to volve the "firmly adsorbed water" at least in the mineral concept, as such an clusion gives support to some reasonable hypotheses concerning the me-hanical properties of the clay water system.

It has generally been assumed that the viscosity of the liquid phase in the lays differed from the viscosity of normal water. Further, it has been assumed at the viscosity of the clay water increased by decreasing distance from the ineral surface. At present we do not know any technical method which per-its a direct determination of a yield value or viscosity of the water adsorbed n the surface of the tiny clay minerals. However, indirectly it seems to be a ossibility for a determination. Under certain conditions there exists a relation etween the coefficient of the self-diffusion in a liquid and the coefficient of iscosity of the same liquid (B. OTTAR 1955). In a previous paper (op. cit. 955) it was shown that the self-diffusion of water in the water phase of satu-ated clays was noticeably lower than the self-diffusion in ordinary free water. Thus, for three different saturated clays, values between 0.12 cm^2 per day and .18 cm^2 per day were found, whereas the diffusion coefficient in free water is nown to be 3 cm^3 per day (JUY HSY WANG 1951—53). The saturated clays ill always have a fairly high water content and the influence of the pore ater will be overwhelming. By water contents lower than corresponding to ll saturation, the result obtained was, however, confusing and irreproducible; is, most probably, due to partial diffusion in the gas phase. By a new techni-ue, this difficulty seems to be overcome. We have now prepared mixtures of ay minerals at relatively low water contents and CCl_4, subsequently we have onsolidated these pastes so that all the voids are filled with carbontetrachlo-de. As water is practically insoluble in carbontetrachloride, there will be no arked diffusion through this phase, but only through the water phase sur-ounding the minerals. By self-diffusion using heavy water as tracer, it was ossible to determine the apparent diffusion coefficient in the sediment and is value could then be recalculated to the water phase. Thus, we found D-alues from 0.08 cm^2 per day in a mixture of finegrained illite with 30 % ater to D = 0.013 % cm^2 per day in a mixture of the same minerals with) % water. Provided diffusion takes place as single molecules, these values orrespond to viscosities from 24 centipoises at 30 % water and 153 centipoises 10 %. If extrapolating these values, we arrive at very high viscosity values

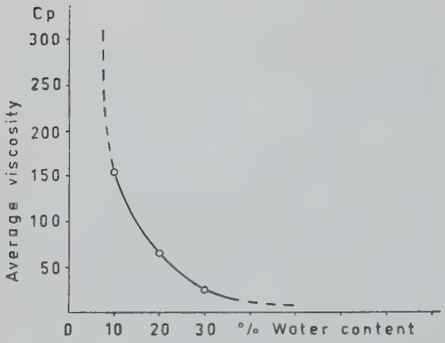

Fig. 8. Relation between calculated average viscosity and water content in remoulded Åserun clay.

in the water phase next to the mineral surface, whereas the normal viscosit coefficient at about 1 centipoise may be present in parts of the free pore wate (Fig. 8). This concept of a pitchlike viscosity in the water next to the mineral may give support to the opinion that the adsorbed water form the “glue” responsible for the cohesion in clays. This primitive hypothesis, however, doe not explain why the adsorbed cations have such an important influence on th strength of a clay at a given water content. The difficulty arose as it was foun that the viscosity and amount of adsorbed water seemed to vary but very littl when the adsorbed cations were changed. At the same time the shear strengt varies considerably.

Another explanation of the adhesion between the minerals in a clay may b raised in this connection, viz. the influence of the variation in the surfac energy of the adsorbed water and the water in the voids. It is generally know that the surface energy of solids is higher than that of liquids. As the fre energy of the water next to the clay minerals is found to be nearer to that o ice than that of water, we have to assume that the surface energy of the adsorbed water might be higher than that of the free pore water. Thus, we hav to take into account an “interphacial tension” between the water closest to th minerals and the free water of the voids. This “interphacial tension” may b suggested to be the reason for adhesion between adjacent minerals and henc for cohesion even in saturated soils. This is in principle the same as the “apparent cohesion” in partially saturated soils: If two solids are partially wette and brought in contact, we know that they will stick to each other because o the surface tension in the concave menisci of the water films. The force require to pull the two solids apart will be proportional to the surface tension and inverse proportional to the curvature radius of the meniscus. By small curvatur radia, these forces will obtain very high values, giving an apparent cohesion i such aggregates. During the process of normal drying we know that the surfac tension will consolidate clays considerably and bend and even crush the mineral

When a saturated soil sample is immerged in water, the action of the surfac tension is concealed, and a wet sand or silt sample will fall apart. Howeve supposing an interphacial tension between the water next to the minerals an the water in the voids, there will be an analogy between such a system and th partially wetted silts in air. However, as we do not know the actual value of the surface tension of the adsorbed water and there obviously is a gradual transition towards the free water, the concept of the interphacial tension is rather obscure. Nevertheless, such an interpretation may not be excluded, and it may be that the influence of the different cations on the interphacial tension could explain why for instance lithium clay has a much lower shear strength than a caesium clay at the same water content. However, there is one observation which stands to contradict such an assumption; that is the fact that a partially dried clay with air in the pores has very much the same strength as when the pores are filled with CCl_4, although the interphacial tension of water towards CCl_4 is less than 2/3 of the surface tension of water.

The Effect of Water upon the Mechanical Properties

Although the mineralogical composition, the grain size distribution and the geological age and origin may differ radically from one clay to another; there are some general features which characterize all clays and separate them from other inorganic soils. The plastic properties of clay-water systems are the most conspicuous and most of the other characteristic properties of clays may probably be linked together with the fundamental origin of the plasticity. From HVORSLEV's experiments we know that if a clay-water slurry is consolidated by a given stress to a given water content, and again unloaded and allowed to swell in water; the shear strength of such a material depends upon the water content and the stress conditions. The reduction in shear strength by unloading is relatively moderate by all clays and may be insignificant as in the case of bentonitic clays. The shear strength of all clays depends on the previous stress conditions to quite another extent than in the silts and sands. This persistent shear strength by unloading must be physically explained by any theory describing the clay-water systems.

As mentioned, V. M. GOLDSCHMIDT found that the typical clay properties, mainly the plasticity, depended on interactions between water and certain leaf minerals. He found that if clay minerals were mixed with non-polar liquids as for instance carbontetrachloride, the mixture behaved as a pure frictional material. He could not find any adhesion under such circumstances but that the shear strength was proportional to applied stress and disappeared when the normal stress was unloaded. Further, he found that it was impossible to obtain mixtures of clay minerals and carbontetrachloride which could be shaped plastically in the same way as mixtures with water or other polar liquids. These were important findings and help us to understand the clay-water systems. GOLDSCHMIDT worked with pre-dried mineral powders and did not try an exchange of water phase in undisturbed or remoulded clay-water samples. Such exchange experiments have been performed by MICHAELS and LIN (1954). They found that the structure and the permeability in prepared mixtures of kaolinite with different liquids at a given void ratio depended on the nature of the fluid. Even when water was used as the moulding fluid and successively was replaced by other liquids, the permeability values differed for different fluids; viscosities and densities taken into account. In these series we may infer that the structure of the mineral skeleton was unaltered by the replacement of one liquid for another. They point to the important fact that a part of the water in clay-water systems should be considered rather a part of the soil particles than a part of the pore fluid.

The consequence of the important work of MICHAELS and LIN is that presence of water in a clay-water system (1) influences the mutual arrangement of the mineral grains and (2) changes them from being rigid silicate sheets into a new type of particles with immobilized hydrogen and oxygen atoms in a more or less rigid arrangement. A "clay-water" particle differs from a dry clay mineral because of the thin adsorbed water envelope. The isotope exchange experiments carried out at the Norwegian Geotechnical Institute confirm this opinion, and we have many reasons to regard the minerals in a clay-water system as thin plates where the external part has a decreasing yield value and modulus of elasticity. In mixtures of clay minerals with non-polar liquids, or when the minerals are dried, the plates must be considered somewhat thinner, but with uniform modulus of elasticity, even in their outermost parts. It seems obvious that systems of so different a character must behave different on remoulding and consolidation and give different structures even at the same void ratio.

It is a well known fact that the macroscopic shear strength and elasticity modulus of clay-water systems increase by drying. At the same time we will have noticeable decrease in volume. In order to investigate the influence of the volume decrease upon the shear strength, we have tried to freeze dry undisturbed clay samples. When such samples are quickly frozen by immersing them into liquid air, there will be negligible or no movement of the liquid phase during the process of freezing. Subsequently the ice can be sublimed off at temperatures well below the freezing point. The frozen clays are placed in a vacuum above a drying agent as for instance phosphorus pentoxide. If a clay is treated in this way, we well notice several interesting features; first that the increase in volume due to freezing is less than what should be expected from the difference in volume between the water content in the liquid state and in the ice state; secondly that there is no change in volume during drying; thirdly we find that the shear strength and modulus of elasticity is much less in the freeze dried clays than in the normally dried clays. In fact the freeze dried clays do not seem to differ very much from the wet clays in their strength values. However, they behave as very brittle materials with a negligible deformation at failure and not as a plastic material. The mutual mineral arrangement in the freeze dried clays was examined by electron-microscope methods, and we regard this arrangement as very close to the mineral arrangement in the undisturbed natural clays (see Fig. 4—5). The importance of this point will be taken up later.

Anyhow, the freeze dried clay behaves as a material very different from a sample of dry clay powder compacted to the same volume on the one hand and a normally dried clay on the other. In the first case, we have no tensile strength, in the second case we have a rather high one. Following up this line, we may replace the air in the freeze dried clays by a non-polar liquid as carbontetrachloride. This may easily be done without any harm to the clay sample. The dried clay does not fall apart and the strength values remain very much the same. If the freeze dried clays are put into water, they will at once disintegrate in the same way as a normally dried clay. If a clay with the voids filled with carbontetrachloride is brought in water, we will have a similar disintegration and carbontetrachloride is ejected from the clay surface in small droplets. This shows that the wetting of the minerals must involve a considerable loss of energy, probably due to the formation of adsorbed water films around each mineral.

Some objections may be raised against the experiments described, mainly because of the fact that the freezing process involved a slight expansion, which may tear the single minerals somewhat apart. However, we may replace the water of a clay be replacement reactions similar to what was done by Michaels and Lin. If a natural undisturbed clay is percolated by alcohol ending up at 100 % concentration, we may remove all the water which normally is considered as pore water and most of the adsorbed water. The system thus obtained behaves as a plastic material even though the plasticity is less pronounced than in the water system. This is similar to what was found by V. M. Goldschmidt on remoulded mixtures obtained from dry clay powder and alcohol. The alcoholic soil has shear strength properties similar to aqueous soils. Subsequent to the percolation, with absolute alcohol, we may bring in a non-polar liquid as carbontetrachloride and we may replace all the alcohol in this way. Even this system has a considerable tensile strength, but has now lost all the plastic behaviour and seems to be very similar to the system of minerals and carbontetrachloride obtained by filling the freeze dried samples.

All the different findings in undisturbed and remoulded clays with a liquid phase being either alcohol or aqueous solutions or a non-polar liquid as carbontetrachloride illustrate the importance of the liquid is of a polar character. The tensile or crushing strength of clays seems, however, not to be fundamentally different in the cases when the liquid is of a polar or a non-polar character, or when the liquid is entirely lacking as in the case of the freeze dried clays, which solely consist of solids and gases. It seems as if the friction theory of Bowden and co-workers may fit in with this system of observations. The clays differ from the typical frictional soils in the case of the plasticity, mouldability and cohesion. At the same time we find frictional properties not very much different from those of sand with open structures. It seems as if the clays as well as the open layered sands represent systems where we may disregard the dilatant component of friction. Sand of open structure will obtain a high shearing resistance by high effective normal pressures just in the same way as a dense sand. When the pressure is released, however, the sands will lose their strength entirely. In the case of clays we know that the shear strength is a function of he consolidation pressure, but that a great part is maintained even when the sample is unloaded and the effective stresses are brought down to zero. This strength is what we call the cohesion. The difference between the clay minerals and the minerals of the sands is primarily that the clay minerals have a surface with a layer of fixed adsorbed water. This is not the case to the same extent with the minerals of the sands. The adsorbed water of the clay minerals has energy properties corresponding to those of a crystalline phase. Thus the innermost water molecules nearest to the mineral surface are to be regarded as a continuation of the mineral itself. This aqueous part of the mineral is, however, different from the other bricks of the mineral lattice because of the high mobility, as was demonstrated by the protium-deuterium exchange experiments. The clay minerals in water must thus be regarded as particles of a very peculiar nature. The innermost part is rigid, whereas the outer layers are soft and the atom groups of the surface can easily interdiffuse.

When any two minerals are brought close to each other, bonds of adhesion between the grains will arise, independent of whether water is present or not. (The influence of the water is quantitative and not qualitative. By a given distance, attraction depends upon the dielectricity constant of the medium in which they float.) Supposing that the two minerals which are brought in contact are of the normal rockforming type as quartz, elastic stresses will arise in the areas around the points of contact, and when the external stresses are released, these elastic forces will tend to separate the minerals again. If, on the other hand, the minerals in question belong to the clay mineral group, they will, in an aqueous system, be surrounded by a layer of adsorbed water. When such minerals are pressed together, the outermost layer of the mineral (the water film) will yield plastically and no or low elastic stresses will arise at the areas of contact. For this reason a subsequent release of the pressure will not bring the minerals totally apart, and they will even in the unloaded state stick together because of the adhesional forces. By dry minerals or with minerals immersed in liquids which cannot be sufficiently adsorbed, deformations will involve elastic stresses in the areas of contact and the material will behave as a pure frictional system independent of whether the minerals are quartz or montmorillonite. The adhesional forces in clay-water systems are mainly of a Van der Waals nature, perhaps also of inoic and covalent character. They depend on the mutual distances between the minerals and the surface cations adsorbed upon them. The cohesion in a clay sample may be regarded as the integral adhesion. A model analogous to the cohesional and frictional properties of clay could be obtained from steel balls and a fine cover of a ductile metal like indium. The thickness of this plating must be very thin, of the order of magnitude 10 Å, and evenly distributed. J. S. McFarlane and D. Tabor (Proc. Roy. Soc. A 202, 244 1950) have shown that when a clean, hard metal ball is pressed into an indium surface, we will obtain a permanent adhesion due to electronic bonds and the tension necessary to break the bonds is of the same order as the normal stres which brought the surfaces together. In the model outlined above, the stee balls represent the clay minerals with the adsorbed ions and the adhesiona forces should mainly be due to the atoms in the steel, whereas the idea of th indium film is to yield and prevent elastic stresses in the areas of contact. (Th model is not quite a good one as the electronic bonds in the model differ very much in nature from the Van der Waals bonds in the clays.)

The consequence of the colloidal chemical view was that the cohesion of soils in addition to the secondary cementation is mainly caused by weak bonds between adjacent minerals. This part of the cohesion is therefore related to the non-dilatant friction and will depend on the number of bonding atoms acting between adjacent minerals and their mutual distance. With clay sediments of given grain distribution curve with a given shape of the grains and a given void ratio, we may have many different distributions of the distances between any two minerals. The variation depends on the mutual arrangement of the minerals. Provided a complete haphazard arrangement of the minerals, there will be one given distribution curve characterizing the distances between the atoms of adjacent grains. Under such circumstances we will have a given integral Van der Waal attraction and a given electrostatic ionic attraction and a given Coulomb repulsion between a single grain on one side of a supposed shear plane and the neighbouring grains on the other side of this plane. Hence the adhesion which is supposed to be the sum of all attractive and repulsive forces will depend as well on the mutual arrangement of the mineral grains as on the nature of the grains. The arrangement of the minerals by a given void ratio is a function of the stress history.

Supposing that the water content of the clay/water system is changed, we will, at the same time, introduce a change in the distances between the grains and the integral attractive and repulsive forces will change. The cohesion term will hence depend on the void ratio, which with saturated soils means the water content. In this case it was supposed that the mineral grains continue to be distributed hazardly without any preferred orientation. We may on the other hand keep the void ratio (the water content) constant and alter the mutual orientation of the grains. The distance distribution function will then change accordingly. We know that it is the short distances, mainly the distances shorter than 15 Å, which are of importance. At greater distances the Van der Waal forces will decrease rapidly and even turn into repulsive forces. Therefore, it is obvious that the mutual orientation of the grains will have an important bearing upon the bonds between the single minerals. Let us suppose that with exactly the same minerals and exactly the same water content but with a very much different orientation of the grains the distance distribution function may be as illustrated in Fig. 9.

As mentioned in an earlier chapter, we have now been able to ascertain the orientation of the minerals in the clay sediments. The stereoscopic pictures show a certain degree of sub-parallelism in the horizontal plane, but mainly haphazard orientation, so that contacts between the corner of one mineral and the plane of another predominate. This is a natural consequence of the formation of the sediment.

Regarding numerous normal non-swelling clay minerals in a suspension where all minerals are far apart and uninfluenced by each others, there will be a very high possibility that two neighbouring minerals are orientated so that

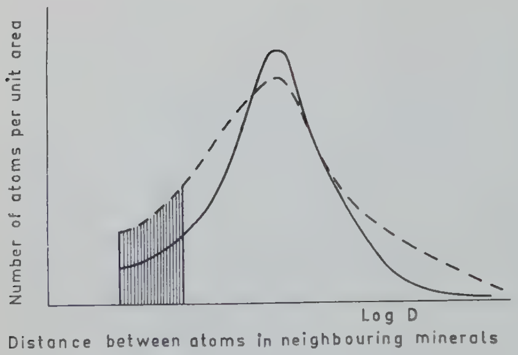

Fig. 9. Schematic illustration of the atomic distance distributions in a clay at constant water content in two different orientations of the minerals, i.e. by two different stress histories. The cross-hedged areas represent the atoms involved in the attraction.

the corner of one mineral is nearest to a plane of another mineral. All other orientation, as for instance that an edge of one mineral should be parallel to the plane of another, or that two planes should be parallel, may be disregarded. If we suppose that the volume decreases regularly, i.e. that we are bringing the minerals closer together without changing their orientation, we will at last arrive at a point where the atoms of the corner of one mineral will affect the atoms of the plane of another mineral. Thus, a bond will be created and further decrease in the volume must take place by an angular deformation between the minerals. This mutual deformation may eventually continue until the edge of one mineral and the plane of the other are in contact, eventually so far that the two planes become parallel. If we had no other orientating forces than the purely mechanical one, the probability for the first case would be definitely much higher than the probability for the second case at a given void ratio.

If we only look upon the original case, viz. grains where all contacts are restricted to corners and planes, it is obvious that mathematically the contact area through a cross section will be equal to zero, as a corner is supposed to be 0-dimensional. Even when we have contacts between an edge and a plane, the contact area must be supposed to be zero, as the edges are supposed to be one-dimensional. Mathematically it will, therefore, not be possible to speak about any area of contact in such a system without giving the corners and the edges a certain area. As long as we are dealing with mass forces, it is obvious that we have to take such an assumption because the Van der Waal forces are acting over a certain distance and we, therefore, have to take a certain depth into account. Looking upon a corner of a mineral as a pyramid, it will be justified to speak about a "contact area" and set this area equal to a cross section through the pyramid at a distance from the point corresponding to the effective average distances to the atoms which are active in the Van der Waal attraction between the pyramid and the plane. As the Van der Waal forces are decreasing at a high power of the distance, it will mainly be the atoms in the point of the pyramid which will cause the attraction, whereas atoms in a distance in above 10—15 Å will only involve an insignificant attraction. For the sake of argument, we may, therefore, assume that the contact area between a corner and a plane will be of the order 10 –100 Å^2 for each point of contact. When dealing with an edge and a plane, we have to take an effective plane through the wedge into account and the area would consequently be of the order 3—10 Å times the length of the contact. The shear strength of a sediment bonded solely by Van der Waals forces and ionic bonds etc. but with no cementation will be proportional to the number of contacts per unit volume in the 2/3 power. If all minerals are forming 3 contacts, this means that the shear strength of a clay paste should be proportional to the number of clay mineral grains per unit area. As the volume of the mineral phase in a unit volume $= \dfrac{100}{100 + GW}$ and the volume of the median mineral = (dv med.)^3. The number of contacts per unit area is $\dfrac{1}{(\text{dv med})^2} \cdot \left(\dfrac{300}{100 + GW}\right)^{2/3}$ Here (dv med) means the median value of the volume diameter

G means the specific gravity of the clay mineral
W means the water content.

The result thus obtained is approximately the same which may be calculated directly from a knowledge of the size and shape of the minerals. Under such conditions we may calculate the area of contact through a cross section of 1 cm^2 in a clay and a thickness equal to the edge length of the clay minerals. Approximately the median dimensions of the minerals in the Norwegian clays are 10^{-4} cm × 10^{-5} cm × 10^{-6} cm = 10^{-15} cm^3, i.e. dv = 10^{-5} cm. Supposing three points of contact for each grain and the contact area for each point between 10^{-15}—10^{-14} cm^2 = 10—100 Å^2 we thus arrive at the conclusion that we have between 10^{-4} and 10^{-5} cm^2 contact planes in a slice of 1 cm^2 and the thickness of 10^{-5} cm, equal to the volume diameter of a clay mineral. Consequently, if the whole shear strength of the soil should be due to the adhesional forces in these points of contact, the shear strength in the contact area must be 10^4 to 10^5 × greater than the shear strength in the clay as a bulk. As an average value we arrive at about 1—10 tons/cm^2, which is the same order of magnitude as the crushing strength of rockforming minerals. However, the strength of the bonds are so poorly defined that it does not seem to have any sense at present to carry on further detailed calculations on this point. It is sufficient that the values arrived at are not completely non-sensial.

The shear strength of sediments will, according to the view presented in this paper, be a function of the area of contacts along a shear plane, independent of how this contact area originated. There will be no fundamental difference between the friction and the cohesion. The difference in behaviour of a clay from that of a sand deposit must be due to the special properties of the clay-water system which permit the areas of contact to remain nearly unchanged by unloading. What is normally called cohesion in soil mechanics means simply the shear strength intersect in a stress/shear strength diagram. Thus, a normally consolidated clay has a shear strength intersect equal to zero, whereas an over-consolidated clay may have a considerable shear strength intersect. It seems unreasonable that the cohesion should arise simply by unloading, as this is a consequence of the vulgar concept. As long as no cementation takes place, the shear strength intersect of an unloaded clay according to the presented view will be simply due to the deformability of the aqueous part of the clay minerals.

Summary

The heat of wetting, the diffusibility of hydrogen and isotopic protium, deuterium exchange, indicate that a part of the water in a clay-water system should be considered as belonging to the mineral phase. The minerals thus consist of a central silicate skeleton with an outher part of aqueous composition. The presence of this outer part is the essential characteristic of the mineral phase in a clay-water system. The typical clay properties as cohesion and plasticity is discussed as a consequence of such minerals. The Bowden friction theory is supposed to be valid in clay-water systems.

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Experimental Kinetic Data on the Formation of Mullite in some Kaolin Clays[1]

By

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Abstract. The rate of formation of mullite has been studied for three different kaolin clays. Two of these contained appreciable amounts of mica as bimineral. The mica present influences and increases the rate of mullite formation. The experimental data show that the formation of the mullite phase at 1 100—1 200° C is not a recrystallization. It is shown that after the exothermic effect at 950° C, and before the formation of the mullite phase as revealed by X-ray diffraction, not less than 80 per cent of the total available Al_2O_3 is present as γ-Al_2O_3. Thus no mullite phase, either totally or partially, can be formed in the strongly exothermic reaction at 950° C.

The kinetic course is treated in two different ways. The first method presumes that the rate limiting step is diffusion-controlled. The course is represented by an empirical time function and a characteristic time constant defined as 50 per cent conversion time. The temperature dependence of the later time constant is given by an Arrhenius' relation with an activation energy of 200 kcal/mole. The second method does not correspond to any reaction mechanism but shows that the course can be satisfactorily described as a first order reaction if the concentration variable is suitably chosen.

Purpose

The purpose of this investigation was to obtain experimental data on the rate of formation of the mullite phase in some kaolin minerals used in the ceramic work going on in this division. It was also desirable that these data would be ample enough to permit a treatment to see if the kinetic course could be simply expressed.

Introduction

By heating kaolin, the chemically bound water is lost at 500—600° C. Metakaolin, whose structure has not yet been elucidated, is then obtained. Further heating will result in a strongly exothermic reaction between 900—1 000° C Full clarity as to the nature of this reaction has not yet been attained. Various suggestions on the interpretation of this exothermic effect have been made, but without any certainty. γ-Al_2O_3 appears in the interval 900—1 000° C, and mullite may be detected at temperatures above 1 000° C. Cristobalite is formed at slightly higher temperatures.

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[1] Lecture given in The Swedish Society for Clay Research on May 5th 1958.

A large number of investigations on the formation of metakaolin and the nature of the strongly exothermic effect has been carried out and published in the literature. The author will only outline three different reactions which have been suggested and are now discussed in connection with the formation of mullite.[1] For more details, the reader will be referred to the excellent literature reviews given by HOLDRIDGE and VAUGHAN (1957), EITEL (1954), GRIM (1953) and RICHARDSON (1951).

INSLEY and EWELL (1935), as well as RICHARDSON (1951), attribute the exothermic effect at 950° C, in the DTA-diagram, to a crystallization of γ-Al_2O_3 from amorphous aluminium oxide present in the kaolin. Mullite is then formed by reaction at higher temperatures between γ-Al_2O_3 and the amorphous SiO_2.

$$\begin{array}{ll} 900\text{—}1\,000^\circ\ \mathrm{C}: & \underset{\text{metakaolin}}{Al_2O_3\cdot 2SiO_2} \longrightarrow \gamma\text{-}Al_2O_3 + SiO_2\ (\text{amorphous}) \\ 1\,000^\circ\ \mathrm{C}\text{—}: & \gamma\text{-}Al_2O_3 + SiO_2\ (\text{amorphous}) \longrightarrow 3Al_2O_3\cdot 2SiO_2 \\ & SiO_2\ (\text{amorphous}) \longrightarrow SiO_2\ (\text{cristobalite}) \end{array}$$

On the other hand, GLASS (1954) considers mullite to be formed in two steps, and the energy evolved at 950° C mainly related to the formation of a primary mullite phase.

$$\begin{array}{ll} 950\text{—}980^\circ\ \mathrm{C}: & \underset{\text{metakaolin}}{Al_2O_3\cdot 2SiO_2} \longrightarrow \underset{\text{primary mullite}}{3Al_2O_3\cdot 2SiO_2} + \gamma\text{-}Al_2O_3 + SiO_2\ (\text{amorphous}) \\ 1\,200\text{—}1\,250^\circ\ \mathrm{C}: & \gamma\text{-}Al_2O_3 + SiO_2 (\text{amorphous}) \longrightarrow 3Al_2O_3\cdot 2SiO_2 + SiO_2 (\text{amorphous}) \\ 1\,240\text{—}1\,350^\circ\ \mathrm{C}: & SiO_2\ (\text{amorphous}) \longrightarrow SiO_2\ (\text{cristobalite}) \end{array}$$

According to GLASS, the amount and size of the primary mullite phase will depend on the degree of crystallization of kaolinite, and on impurities associated with the clay. The largest amount of primary mullite will be obtained from a well crystallized kaolinite free from intergrown mica.

COMEFORO, FISCHER and BRADLEY (1948), consider mullite to be formed during the exothermic reaction at 950° C by a rearrangement of the lattice. Even JOHNS (1953), and ROY, ROY and FRANCIS (1955) state that the exothermic reaction at 950° C is connected with the formation of mullite.

According to them, the mullite phase formed in the reaction at 950° C cannot be detected by X-ray diffraction because of the very small size of the crystals. Further heating at higher temperatures causes the mullite crystals to grow and recrystallize and thus to become large enough to give X-ray diffraction peaks. Consequently they interprete the often observed presence of γ-Al_2O_3 as incidental and not as a primary step in the reaction series.

$$\begin{array}{ll} 950\text{—}1\,000^\circ\ \mathrm{C}: & Al_2O_3\cdot 2SiO_2 \longrightarrow 3Al_2O_3\cdot 2SiO_2 + SiO_2\ (\text{amorphous}) \\ 1\,000^\circ\ \mathrm{C}\text{—}: & \text{recrystallization of the mullite phase} \\ & SiO_2\ (\text{amorphous}) \longrightarrow SiO_2\ (\text{cristobalite}) \end{array}$$

We shall not, at this stage, attempt to decide which of these theories on the formation of mullite is the right one. We will only establish that the mullite

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After this article was written, Brindley and Nakahira have suggested still another reaction mechanism involving a silicon spinel, see Nature **181** (1958). May 10, p 1333.

phase in any case cannot be formed before the strongly exothermic reaction at 900—1 000° C.

I cannot, however, avoid emphasizing the two following reasons for the lack of clarity of the high temperature reactions of kaolinite. Within large temperature intervals, it is a matter of phase kinetics rather than one of equilibrium, and for that reason it is not sufficient to give the heating temperature only as done in most investigations. Furthermore, most studies of these reactions give only qualitative information regarding the presence of crystalline phases without any attention being paid to quantitative determinations of the phases present.

Investigations in the course of which mullite has been quantitatively determined, may be divided into two groups depending on the method of analysis. The larger of these two groups, which may be represented by BLEY (1925), MIEHR (1928), YOSHIOKA (1933), PARMELEE and RODRIGUEZ (1942), AVGUSTINIK and USHAKOVA (1945), BUDNIKOV and SHMUKLER (1946), DEMIDOVA and GONCHAROV (1951), and HANSSON (1955), has used different variants of a chemical method. The common principle of these methods is based on the different rates of dissolution of the phases in hydrofluoric acid, so that mullite will be determined as insoluble residue using or not using a correction factor for the dissolved part of the mullite phase. Characteristic for this group of investigations is the conception that mullite begins to form at 1 100—1 200° C, but that further heating, to temperatures as high as 1 500° C, is required for complete formation of the mullite phase. As stated before (LUNDIN 1955), because of the very small size of the crystallite in the mullite phase and the varying size of the crystals due to different heating conditions, the chemical methods give misleading results as to the amount of mullite formed. Therefore we must conclude that the investigations using these chemical methods are of little value for the estimation of the rate of formation of mullite.

The other but smaller group includes investigations where X-rays have been used for the quantitative determination of mullite. Already in 1925 NAVIAS determined the amount of mullite in Al-kaolin fired to cone 9 ½ (max. temp. 1 255° C with a heating rate of 100° C/hr); his results were of the same order of magnitude as the theoretically possible maximae. Unfortunately X-ray diffraction was used later on almost exclusively for qualitative purposes. Occasional quantitative determinations of mullite in fired kaolins, were performed by HARVEY and BIRCH (1936), and TUTTLE and COOK (1949). They obtained mullite percentages of about 50 % after only a few hours firing at 1 200° C. The mullite content did not increase further when the firing temperature was raised.

A third method can be used in studying the formation of mullite, but not enough attention has yet been paid to it. This is the differential thermal analysis. The reason for this is the tendency to take differential thermal curves only for temperatures below 1 100° C. In the case of kaolin clays one or two exothermic peaks are obtained above 1 000° C. The first one appears at 1 150—1 250° C and is connected with the formation of the mullite phase (POTAPENKO 1934, BUDNIKOV and GEWORKJAN 1951, GLASS 1954, HOLDRIDGE and VAUGHAN

1957). The second peak occurs at slightly higher temperatures and refers to the crystallization of cristobalite (GLASS 1954). The differential thermal analysis is thus a fast method for getting information about the temperature interval of the mullite formation, but this information is not so easy to apply to other firing conditions.

The only investigations of kinetic character are those of BUDNIKOV (1953). He investigated the rate of formation of mullite in a Prossnajkowsk-kaolin, among others, and found that the reaction was of the first order, and that the ratio of the reaction rates was approximately 3 for an increase in temperature from 1 200° C to 1 300° C. A calculation shows that this corresponds to an activation energy of about 50 kcal./mole. Budnikov's investigation may be criticized by calling attention to the fact that the mullite content was determined by the chemical method, his results therefore being doubtful. Moreover it is worth mentioning an earlier investigation by BUDNIKOV and SHMUKLER (1946), where they represented within a relatively small interval the time dependence with an empirical equation familiar to all ceramists, i.e.

$$m = a \log t + b$$

What Remains to Be Elucidated?

Of interest is to study how the degree of crystallinity of kaolinite, and the nature and amount of the biminerals influence the rate of formation, the equilibrium value and the crystal size of the mullite phase in first hand but also of the cristobalite phase.

As for the reaction during which mullite is formed, the nature of the reaction components and the mechanism of the rate-determining step are still unknown. Information concerning the time function and the magnitude of the activation energy are desirable.

Further studies on the position of the mullite crystals, relatively to the original kaolinite crystals are also desirable. In the literature there are different opinions and contradictory experimental observations as to a possible orientation of the mullite crystals.

The experimental work described in the following pages, will elucidate some of these points.

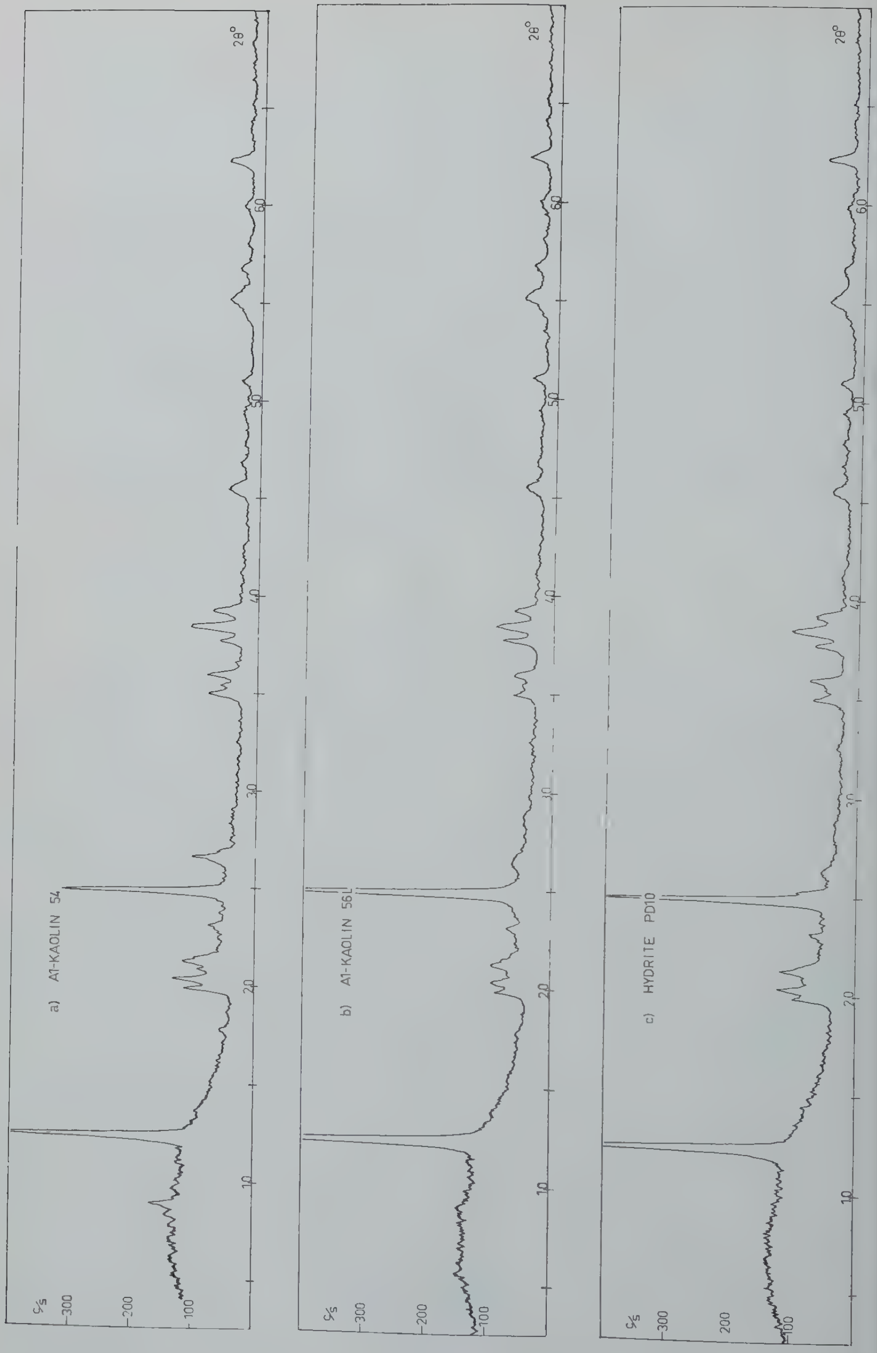
Description of Raw Materials

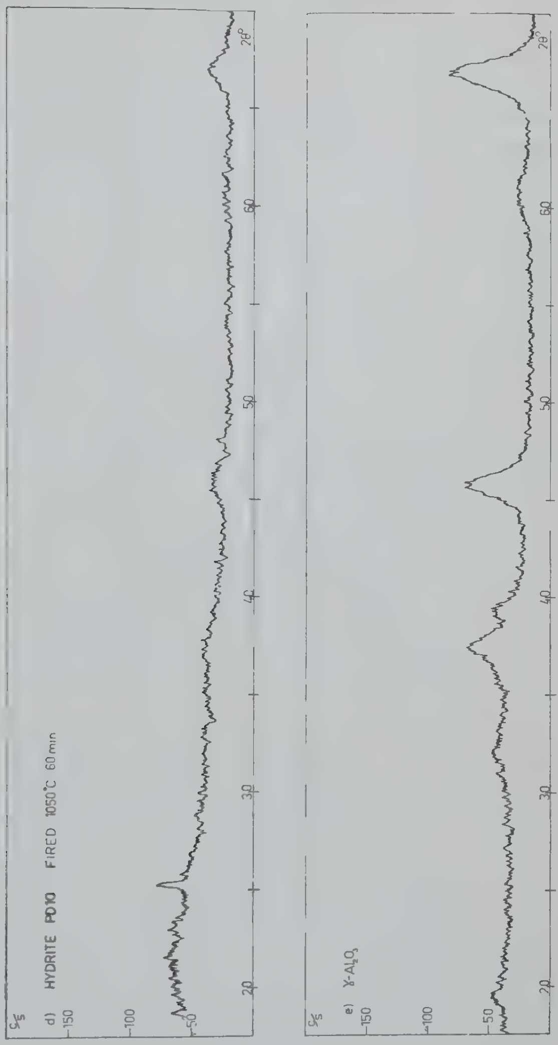
Three kaolin clays have been used by the author in his investigation

1) Al-kaolin 54
2) Al-kaolin 56 L
3) Hydrite PD 10

Their chemical compositions are given in Table 1, their X-ray diffraction diagrams in Fig. 1, and their particle-size distribution curves in Fig. 2.

Al-kaolin 54 is an English China Clay supplied by the English China Clays Sales


a) A1-KAOLIN 54
b) A1-KAOLIN 56L
c) HYDRITE PD10
c/s
300
200
100
10
20
30
40
50
60
2θ°



ig. 1. X-ray diffraction dia-
rams.
a) Al-kaolin 54
b) Al-kaolin 56 L
c) Hydrite PD 10
d) Hydrite PD fired at 1 050°C for 60 minutes
e) γ-aluminium oxide

Co, St Austell, Cornwall. The kaolinite present is well crystallized as shown by the riclinic X-ray diffraction diagram and by well formed crystals observed with the lectron microscope. On the other hand it contains both quartz and mica as biminerals. The amount of quartz was determined by X-ray diffraction as 2.2 ± 0.2 %. The mount of mica calculated as muscovite from the alkali content is 14 %.

Al-kaolin 56 L is the $< 2\ \mu$ fraction from Al-kaolin 54, obtained by a fractional edimentation carried out by the author. This fractionation causes the amount of imineral to decrease. Quartz could not be detected in this clay by X-ray diffraction. The mica content calculated in the same way as above is 7 %.

Hydrite PD 10 is a treated American kaolin obtained from the Georgia Kaolin Co. Elizabeth, N. J. X-ray diffraction shows that the kaolinite present is well crystallized. This kaolin clay is very pure, with no other bimineral detectable by X-ray diffraction out anatase. The anatase content is estimated from the chemical analysis to be 1.4 %.

Table 1. Chemical analyses of the kaolins

	1 Al-kaolin 54 %	2 Al-kaolin 56 L %	3 Hydrite PD 10 %
SiO_2	47.72	46.1	45.30
TiO_2	0.05	0.2	1.44
Al_2O_3	36.44	38.5	38.38
Fe_2O_3	0.44	0.5	0.30
FeO	0.11	—	—
MgO	0.26	0.2	0.25
CaO	0.13	0.3	0.05
Na_2O	0.13	0.03	0·27
K_2O	1.49	0.8	0·04
Ign. loss	13.19	13.4	13.97
Total	99.96	100.0	100.0

Analysis 1 performed by A. Aaremäe, Geological Survey of Sweden
Analysis 2 from O. Frismark, AB Iföverken
Analysis 3 from Georgia Kaolin Co.

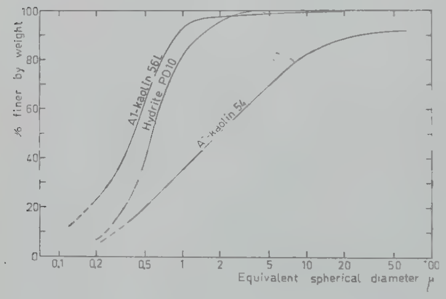


Fig. 2. The particle-size distribution curve of the kaolin clays.

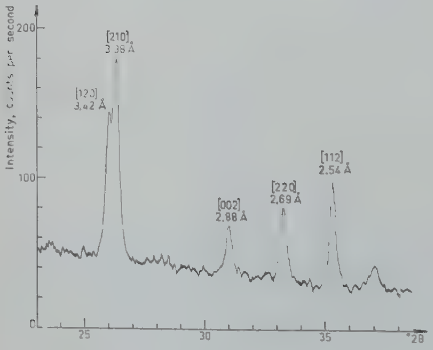


Fig. 3. Part of the mullite diffraction diagra showing the positions and intensities of th interferences discussed.

Pretreatment of the Material and Firing of the Samples

The kaolins were mixed with water until a proper plasticity was reached, homogenized, and moulded in a vacuum piston extruder into a column which was then cut int cylinders of appropriate lengths. In the case of Al-kaolin 56 L, the samples were 30 mm long and 20 mm in diameter. As for Hydrite PD 10 the material supply was short an the samples had to be smaller, 30 mm long and 10 mm in diameter. The samples were dried and prefired at 600° C for one hour, to dehydrate the kaolinite.

The samples were fired in a kiln specially built to give a uniform temperature throughout the firing chamber. The kiln was equipped with silicon carbide heating elements. The temperature was regulated with a Wheelco Capacitrol regulator with thermal resetting. The temperature was measured in a circuit separated from the regulator with a platinum-platinumrhodium thermocouple with the cold junction in melting ice. The thermocouple was checked by the wire method against the melting point of gold; a temperature of 1 062° C was obtained. The 1° deviation is within the experimental error and no temperature correction was required. The accuracy of the temperature regulation was ± 2° C.

The time necessary to heat a larger sized sample from room temperature to 1 100° C was determined as follows. A hole was drilled in the clay sample for insertion of the thermocouple hot junction. The sample was placed in the kiln and the temperature was followed on a continuous recorder connected to the thermocouple. The temperature was raised to within 2° of full temperature in 10 minutes; no overtemperature was observed.

To reduce the time required to heat up to full temperature, the samples were preheated for 10 minutes in a separate kiln at 800° C, before they were placed in the firing kiln. The sample was placed close to the thermocouple junction. The time required for the thermocouple junction to regain the full temperature was 2—3 minutes. The firing time was taken from the time when the thermocouple junction reached firing temperature. In the experiments the firing temperatures were selected to give relatively low reaction rates in order to minimize the influence of the heat of the mullite formation and of the discussed heating up time.

When the firing was completed, the samples were taken out and left to cool in the air. They were then crushed in a steel mortar and finely ground in a mechanical agate mortar.

Description of the Mullite Analysis

The X-ray diffraction analysis of the mullite percentage was made as relative measurements by the internal standard method using calcium fluoride as a reference substance.

The measurements were made on a Philips X-ray Diffractometer PW 1051. The copper radiation was used with a Ni-filter (40 kV 20 mA). The diffraction diagram was recorded automatically, and all measurements were made from these recordings.

The strong double interference [120 + 210] at 26.1° (Fig. 3) was used as measurement interference for the mullite. In a previous investigation (Lundin 1955), the weaker interferences [220] at 33.2° and [112] at 35.2° were used. However, these weak interferences are not suitable in a kinetic study such as this, where reliable determinations are required of low mullite percentages. For Al-kaolin 54 which contained quartz, the measurement interference of mullite, at 26.1°, partly overlapped the quartz interference at 26.7°. Knowing the appearance of the mullite peak in the quartz-free Al-kaolin 56 L, there was no great difficulty in determining the interference contribution of the quartz. The peak due to anatase, at 25.3°, which was present in the Hydrite PD 10 preparation, did not disturb as it could easily be separated. γ-Aluminium oxide and cristobalite could also be present in the samples in addition to mullite. Neither of these compounds has interferences which disturb the selected measurement interferences of mullite or calcium fluoride (3.15 Å at 28.3°). It should be pointed out that in this case cristobalite gave no detectable interference at 3.14 Å. The possible presence of corundum was checked with the strong and free interference 2.08 Å at 43.3°.

For each sample the interference were measured five times with different preparations (Table 2). The intensities of the interferences were evaluated by measuring the

Table 2. Determination of mullite by X-ray diffraction analysis.
Sample: Hydrite PD 10 fired 18 hrs at 1200° C

Fluorite 3.15 Å 28.3° Counts	Mullite [120,210] 26.1 Counts
5 960	14 240
5 890	14 270
6 000	14 600
5 850	14 160
5 590	14 100
Intensity ratio	2.39
	2.42
	2.43
	2.42
	2.52
Mean	2.436
Range	0.13
Standard deviation	0.056
Mullite content	52.8 %
Standard deviation	1.2 %

areas of the peaks planimetrically. The planimeter scale was set to give a direct reading of the number of integrated impulses. The standard deviation for planimetric measurement of an area of 14,000 impulses, was determined from a series of 10 readings as 20 impulses, i.e. 0.14 %. The error introduced by using the planimetric method for evaluating the peak area thus makes only an insignificant contribution to the total standard deviation within each group of measurements.

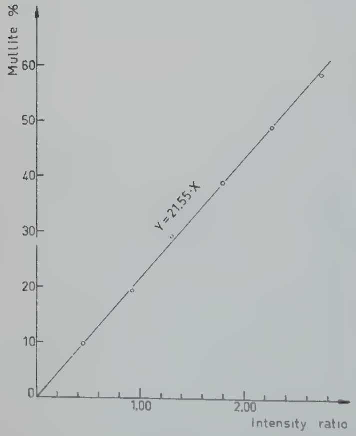


Fig. 4. Mullite calibration curve for the X-ray diffraction analyses. The equation of the regression line is $y = 21.55\ x$ where y is the mullite percentage and x is the intensity ratio. The 95 % confidence range on the slope is $\pm$ 0.26.

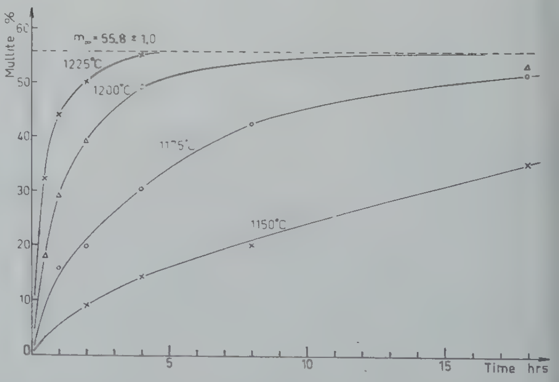


Fig. 5. The mullite percentage as a function of the firing time at different temperatures for Hydrite PD 10.

Table 3. Determination of mullite by X-ray diffraction analysis. Standard sample data for calibration curve

Interferences used:
Mullite 3.42 Å [120] + 3.38 Å [210] at 26° 2Θ
Fluorite 3.15 Å at 28.25° 2Θ

Mullite %	Intensity ratio	S. d.
9.8	0.45	0.02
19.5	0.93	0.05
29.3	1.30	0.04
39.0	1.79	0.06
48.8	2.26	0.03
58.5	2.74	0.10

The mullite used in the calibration mixtures was prepared from an insulator porcelain, by treating 8.0 g of finely ground porcelain with 40 % hydrofluoric acid at 0° C, for six hours.

The mullite was not absolutely pure containing some quartz. The quartz content, determined by X-ray diffraction analysis, was 2.5 ± 0.3. The mullite content was thus put to 97.5 %.

Feldspar glass was used as diluting component in the calibration mixtures. The glass was prepared by melting Hestra potassium feldspar in a high frequency furnace at ca 1 500° C, for 60 minutes. X-ray diffraction showed that only traces of quartz were present. Calcium fluoride, precipitated and recrystallized at 700° C for 20 minutes, was added as reference material in the proportion of 10 %.

The specimen was prepared by pressing in the powder by hand in a round perspex cell. The specimen was rotated in the focusing plane during the measurement. The recording data were as follows:

Diffraction region	29.00—24.00° 2Θ
Goniometer velocity	0.25° 2Θ/min
Paper speed	2 cm/min
Slits	1°
Rate meter	4
Time constant	8 sec.
Multiplier	1.0

Measurements were made with calibration mixtures containing 10, 20, 30, 40, 50 and 60 % mullite. The results are summarized in Table 3; the calibration curve in Fig. 4 has been drawn as a straight line.

Experimental Data

The analytical results for samples from the different firings are given in Tables 4, 5 and 6. The formation of mullite in the different kaolins is shown in Fig. 5—7, with the percentage of mullite expressed as a function of the firing time.

The time functions were determined for 4—5 different temperatures at 25° intervals.

The differences in the rate of mullite formation for the three raw materials are rather large. The rate is lowest for the purest kaolin, Hydrite PD 10, and

Table 4. Mullite content in samples of fired Hydrite PD 10

Temp. ° C	Time, hrs	Mullite, %	S. d. %	Temp. ° C	Time, hrs	Mullite, %	S. d. %
1 150	2.00	8.9	0.9	1 200	0.50	18.0	1.4
	4.00	14.2	1.0		1.00	29.0	0.9
	8.00	20.1	1.1		2.00	39.1	1.3
	18.00	35.1	0.6		4.00	48.8	1.1
	46.00	51.4	2.0		8.00	54.5	1.3
					18.00	52.8	1.4
1 175	1.00	15.8	0.7		36.00	56.2	1.1
	2.00	19.7	0.7				
	4.00	30.3	1.4	1 225	0.50	32.2	1.2
	8.00	42.2	1.6		1.00	44.0	0.7
	18.00	51.2	1.7		2.00	49.9	1.5
	45.00	56.2	2.6		4.00	54.9	1.4
					44.00	55.1	1.6

Table 5. Mullite content in samples of fired Al-kaolin 56 L

Temp. ° C	Time, hrs	Mullite, %	S. d. %	Temp. ° C	Time, hrs	Mullite, %	S. d. %
1 075	17.00	12.2	1.2	1 150	1.00	27.8	1.7
					2.00	40.4	2.1
1 100	2.00	10.9	1.9		4.00	49.5	1.2
	7.00	16.4	0.7		10.00	54.4	2.2
	18.00	24.8	1.5				
	28.00	34.5	1.0	1 175	0.50	34.9	1.9
					1.00	48.3	0.9
1 125	1.00	11.3	0.7		2.00	51.3	1.5
	2.00	18.7	0.5				
	4.00	25.0	2.2	1 200	18.00	52.9	0.9
	8.00	35.6	1.1				
	17.00	49.9	1.2				

Table 6. Mullite content in samples of fired Al-kaolin 54

Temp. ° C	Time, hrs	Mullite, %	S. d. %	Temp. ° C	Time, hrs	Mullite, %	S. d. %
1 050	6.00	11.0	1.1	1 125	0.50	19.2	0.7
	24.00	16.2	1.0		1.00	23.8	1.4
	45.00	19.8	0.9		1.50	28.8	2.1
					2.00	33.1	2.2
1 075	1.00	10.9	0.5		4.00	41.3	1.5
	2.00	12.4	1.4		10.12	48.0	1.5
	4.00	14.6	1.4		18.00	48.3	1.2
	10.12	19.6	1.1				
	18.00	23.9	0.6	1 200	3.00	49.5	1.9
	42.00	38.1	1.4		9.00	46.7	1.8
					18.00	50.0	1.7
1 100	0.50	12.9	1.8				
	1.00	17.4	0.7				
	2.00	20.8	0.7				
	3.00	23.3	1.2				
	4.00	27.4	0.9				
	10.12	38.4	0.6				
	18.00	48.3	2.6				

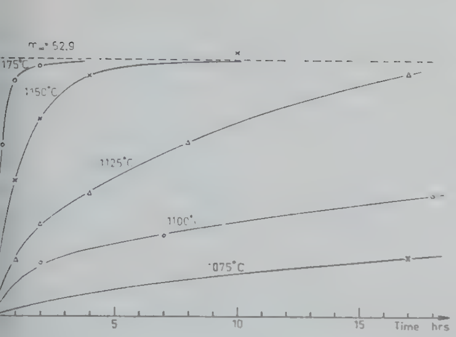


Fig. 6. The mullite percentage as a function of the firing time at different temperatures for Al-kaolin 56 L.

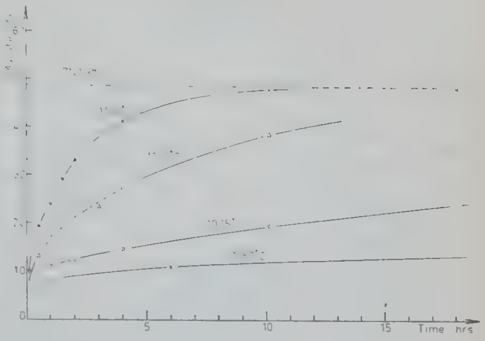


Fig. 7. The mullite percentage as a function of the firing time at different temperatures for Al-kaolin 54.

highest for Al-kaolin 54, which had the largest mica content. The temperatures required to give 95 % mullite conversion in 60 minutes were:

Hydrite PD 10	1 250° C
Al-kaolin 56 L	1 180° C
Al-kaolin 54	1 160° C

Since in all three kaolins the kaolinite present was well crystallized and well formed, it was concluded that the presence of the biminerals had influenced and increased the rate of formation of mullite.

The biminerals present were anatase in the Hydrite PD 10 and quartz and mica in the Al-kaolins.

The anatase was partially dissolved in the temperature interval used for the determinations. It is difficult to estimate the extent to which it increases the rate of formation, above that for an absolutely pure kaolinite. According to the old mullite activator concept given by PARMELEE and RODRIGUEZ in 1942, TiO_2 is not a particularly good activator. However, the old activator concept is probably not applicable in this case.

The analyses show that within the 1 050—1 125° C firing interval used for the determinations, the quartz present in Al-kaolin 54 is not dissolved to any appreciable extent, but instead behaves as an indifferent phase. The X-ray diffraction analysis shows that a quite noticeable solution of quartz first occurs, when firing at 1 200° C. The reaction rate cannot therefore have been influenced by the presence of quartz.

The main difference, between the three kaolins, lies in the mica content. Hydrite PD 10 contains only very small traces of mica, while Al-kaolin 56 L contains 7 %, and Al-kaolin 54, 14 %. The presence of mica must now have two different effects.

In the case where kaolin consists of a mixture of kaolinite and mica it must be expected that there will be different rates of formation of mullite for the two dehydration products. Since the alkali metal oxides are concentrated in the mica anhydrite, it can be expected that mullite will be formed here at a

Table 7. Comparison of determined and theoretically calculated mullite content

	Determined mullite %	Theoretically calculated mullite %		
		1	2	3
Hydrite PD 10	55.8 ± 1.0	62.1	61.4	59.7
Al-kaolin 56 L	52.9 ± 1.0	61.8	60.2	56.9
Al-kaolin 54	48.5 ± 1.0	58.5	54.9	51.8

1. calculated by assuming that no melt is formed
2. active $R_2O = K_2O + Na_2O$
3. active $R_2O = K_2O + Na_2O + MgO + CaO + FeO$ (according to Shelton)

Composition of the melt .... 7.5 % R_2O
10.0 % Al_2O_3
82.5 % SiO_2

higher rate, or equivalently expressed, at a lower temperature. It is difficult to find any clear proof of this assertion out of the literature, but the present author thinks it is supported by the results of SUNDIUS and BYSTRÖM (1953). At the same time it should be pointed out that the high temperature phases formed from mica anhydrite may be quantitatively as well as qualitatively distinguished from those formed in kaolinite. However, there was no indication of corundum in any of the fired samples of the Al-kaolins.

The mica phase present appears also to influence the rate of formation of mullite in the kaolinite. This is explained by assuming that the alkaline ions from the mica reaction products, whether in a highly viscous melt or in a solid phase, diffuse into the mixture of aluminium oxide and amorphous silica obtained from the kaolinite. In this way, the presence of alkaline ions increases the rate of formation of the mullite phase. It is difficult to say with certainty whether the increased rate of crystallization depends on an increase in the amount of active melt or on the breaking up of the silica phase to give a higher diffusion rate for the reactants. Nevertheless many facts indicate the presence of a molten phase, from which the mullite crystallizes.

According to the old mullite activator concept (PARMELEE and RODRIGUEZ 1942), the alkali metal oxides K_2O and Na_2O were inactive and did not affect the amount of mullite formed as determined from the residue insoluble in hydrofluoric acid. However, this insoluble residue in the chemical determination of mullite, might be better regarded as a measure of the recrystallization effect and the crystallite size of the mullite phase than a measure of the mullite percentage (LUNDIN 1955).

The mullite percentages in the fired kaolins, after complete conversion of mullite at 1 200° C, are given in Table 7. They are compared there with theoretical values calculated in different ways. On the one hand there is theoretical maximum calculated regardless of the presence of any melt, as was done in the older literature, and on the other hand the theoretical maximum obtained from SCHAIRER and BOWEN's (1947) phase diagram for K_2O — Al_2O_3 — SiO_2. In the latter case, the equivalent amount of R_2O was taken firstly as $K_2O + Na_2O$, and secondly as $K_2O + Na_2O + CaO + MgO + FeO$ ac-

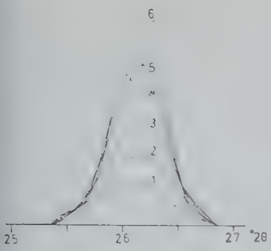


Fig. 8. The growth of the mullite interference [120, 210] from samples of Hydrite PD 10 fired at 1 200°C.

No.	Firing time	Mullite content
1	0.5 hrs	18.0 %
2	1.0	29.0
3	2.0	39.1
4	4.0	48.8
5	8.0	54.5
6	36.0	56.2

cording to the suggestion of Shelton (1948). It should be pointed out that the experimental values for the mullite percentages are not determined in a system in equilibrium because cristobalite is only partly crystallized. However, the mullite percentage is affected very little by the formation of cristobalite.

There is only a partial and insignificant crystallization of cristobalite during the formation of mullite from these three kaolins. The temperature interval for the formation of cristobalite is different for each of the three materials and is highest for Hydrite PD 10 and lowest for Al-kaolin 56 L.

Phases Present During the Formation of Mullite

Phases present during the formation of mullite will be mentioned before discussing the kinetics. X-ray diffraction recordings show the presence of γ-Al_2O_3 only. There are no indications of any mullite phase being present prior to the formation during the reaction of that observed by X-ray diffraction. The mullite interference doublet at 26° appears above the background and increases with only a slight decrease of the half-value width (Fig. 8). If there were a continuous recrystallization of a mullite phase already formed, an extremely broad interference would first occur. This interference peak would then decrease in width, while the intensity (i.e. the interference peak area) remained largely unchanged. That is not the case.

The γ-Al_2O_3 phase is present before the mullite begins to form. With these kaolins this can be shown by X-ray diffraction diagrams of samples fired at 1 000° C for 60 minutes. At higher temperatures, the γ-Al_2O_3 interference are more marked because of recrystallization. The γ-Al_2O_3 phase is consumed at about the same rate as mullite is formed. However, no quantitative measurements of this were made.

The γ-Al_2O_3 content of Hydrite PD 10 fired at 1 050° C for 60 minutes was estimated as follows. A γ-Al_2O_3 preparation obtained by heating bayerite $Al(OH)_3$ at 700° C for 30 minutes was used for calibration. This γ-Al_2O_3 preparation gave the same interference peaks as the γ-Al_2O_3 phase in the fired kaolins, without any deviations as to the positions of the peaks or the relative intensities. The half-value width was also about the same size. The interference peaks coincided exactly with those given by Rooksby 1951. Magnesium oxide was added as reference substance in the proportion of 10 %. The peak at 1.39 Å was used for determining the γ-Al_2O_3 and that at 1.49 Å for MgO. A calibration mixture with 50 % γ-Al_2O_3 gave an intensity ratio of 3.46, and the unknown sample gave 2.44. Linear interpolation gave 35 % γ-Al_2O_3 with a 95 % confidence range of ± 6 %. The total available Al_2O_3 is 44.6 %, so that 80 % of the alumina is present as γ-Al_2O_3. The other two kaolins under the same firing conditions contained about the same amount of γ-Al_2O_3.

The course followed by the changes might be: solution of the γ-Al_2O_3 in the Al_2O_3 — SiO_2 — R_2O melt followed by crystallization of the mullite from the melt. The rate limiting step may thus be either the solution of the γ-Al_2O_3 or the precipitation of the mullite.

Kinetics of the Mullite Formation

The experimental data given above are sufficient for kinetic evaluation. Two approaches are possible. The first involves the determination of the rate limiting stage in the reactions and processes taking place. If this is a chemical reaction, the order, rate constants and activation energies can be studied and measured. If it is a diffusion process a theoretical mathematical analysis can be made of a simplified hypothetical model to give a functional relationship including diffusion constants. The second way is not concerned with the nature of the rate limiting processes but involves the development of satisfactory relationships which give the experimental data in a suitable form for practical use even though the theoretical background may be uncertain. The second approach will be used here.

The experimental data available will be treated in two ways. The first one which starts from the assumption that the rate limiting step is diffusion controlled has in principle the correct background. This method gives

1) an empirical relationship, shown graphically, which expresses the dependence of the mullite formation on concentration and time,
2) a characteristic rate constant with the dimension of time and
3) an activation energy which gives the temperature dependence.

The second treatment is intended to demonstrate that a simple description of the course of the reaction can be given although this does not correspond to any reaction mechanism. Suitable choice of the concentration variables allows the reaction to be expressed satisfactorily as a first order reaction. The latter treatment is unjustifiable on a theoretical basis but can be of practical use because of its simplicity. It gives

1) a characteristic rate constant with a dimension of inverse time and
2) an activation energy.

Of these two methods of treatment the first one (A below) is probably the most suitable from all points of view. It has a sound theoretical basis and at the same time allows the applications of very simple calculations.

In the kinetic treatment it should be noted that the Al-kaolins are mixtures of two mineral components, and that the mullite formation therefore can no

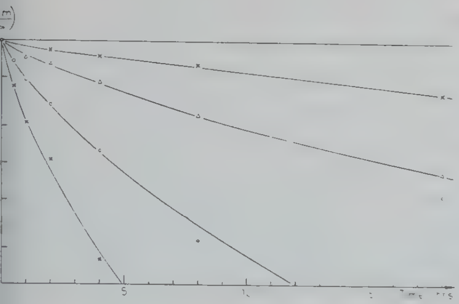


Fig. 9. Plot of $\log\left(\frac{m_\infty - m}{m_\infty}\right)$ against time at different temperatures for Hydrite PD 10.

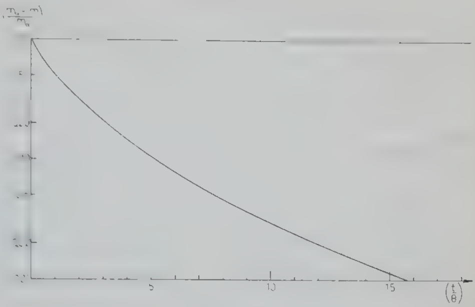


Fig. 10. The function $\log\left(\frac{m_\infty - m}{m_\infty}\right) = \varphi\left(\frac{t}{\Theta}\right)$ for the formation of mullite in kaolinite. Θ is the 50 % conversion time.

be treated as a single homogeneous process. It should however be possible to treat the Hydrite PD 10 as a homogeneous material. There will therefore be differences in the treatment of the data for the homogeneous Hydrite PD 10 and for the mica-containing Al-kaolins.

Application of Method A for the Hydrite PD 10

The rate limiting stage is here regarding as a pure diffusion process. The dependence on concentrations and time can be written

$$\frac{m_\infty - m}{m_\infty} = f\left(\frac{t}{\Theta}\right) \qquad (1)$$

where m_∞ = the mullite percentage of the system when the reaction is complete ($t = \infty$)

m = the mullite percentage at a time t

Θ = a characteristic time constant

Since no hypothetical model has been set up for the calculation of the diffusion process there is no mathematical analytical expression for the function f() and there is no information about the factor composition of the constant Θ. For Hydrite PD 10, Fig. 9 shows the relationship

$$\log\left(\frac{m_\infty - m}{m_\infty}\right) = g(t)$$

for the different temperature levels. The same value of m_∞ has here been used, as it is clear from the phase diagram that m_∞ is only slightly dependent on the temperature in the interval used. These experimental data allow a graphical expression of the function (1) which is given in Fig. 10 in the form

Table 8. Calculation of the 50 % conversion time for Hydrite PD 10

Mullite content m %	$\frac{m_\infty - m}{m_\infty}$	$\left(\frac{t}{\Theta}\right)$	1 225° C		1 200° C		1 175° C		1 150° C	
			t	Θ	t	Θ	t	Θ	t	Θ
10.0	82.1	0.28	0.09	0·322	0.25	0.893	0.67	2.39	2.35	8.4
20.0	64.2	0.62	0.22	0.355	0.56	0.903	1.90	3.06	7.60	12.3
30.0	46.2	1.19	0.44	0.370	1.08	0.907	3.80	3.19	13.9	11.7
40.0	28.3	2.30	0.80	0.348	2.05	0.892	6.90	3.00	23.5	10.2
50.0	10.4	5.00	1.80	0.360	4.40	0.880	15.5	3.10	41.0	8.2
t in hrs Θ in hrs ..		Θ MV	0.351		0.895		2.95		10.2	
m_∞ = 55.8 %		$\left(\frac{1}{T}\right) \cdot 10^4$	6.676		6.789		6.906		7.027	

E = 192 kcal/mole. 95 % confidence range ± 29 kcal/mole.

$$\log\left(\frac{m_\infty - m}{m_\infty}\right) = \varphi\left(\frac{t}{\Theta}\right) \qquad (2)$$

As long as the structure of the constant Θ is unknown it may be fixed arbitrarily. In this case Θ can be suitably defined as the time required for 50 % conversion of mullite at the particular temperature. Other levels could also be chosen for this definition but the 50 % conversion was considered best since this level is easier to evaluate from differential thermal curves than a level of for instance 95 or 99 %. The time constant Θ can now be calculated from experimental data by forming for the same m the quotient of the time t required at the used temperature to the (t/Θ) out of Fig. 10. The values given in Table 8 were obtained for Hydrite PD 10.

The 50 % conversion time Θ is temperature dependent and can be expected to obey the Arrhenius relation

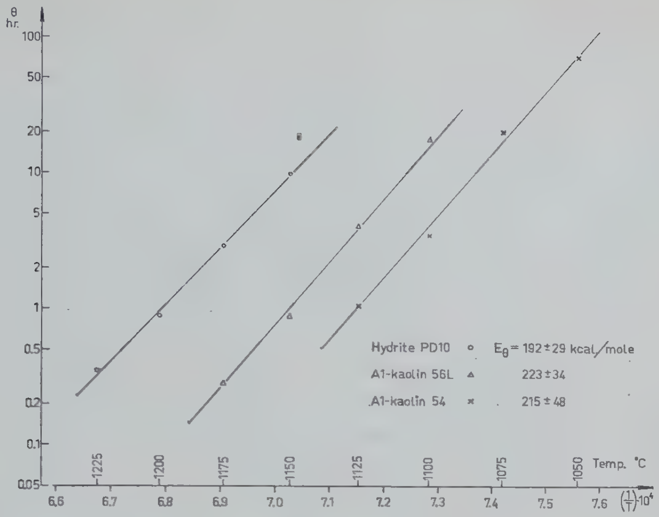
$$\Theta = a \cdot e^{\frac{E}{RT}} \qquad (3)$$

where a = constant with the dimension of time
E = an activation energy

The calculated Θ values give the activation energy from the slope of the straight line which is obtained by plotting log Θ as a function of $(1/T)$ (Fig. 11). This gives a value of 192 kcal/mole for the activation energy. This value is about four times larger than that given by Budnikov, but Budnikov's low values are due to taking the residue after the hydrofluoric acid treatment as equivalent to the content of mullite, which is not the case.

The kinetics for mullite formation in Hydrite PD 10 are covered by the function of time given in Fig. 10 and the Arrhenius equation for the rate constant given in Fig. 11.

The time function given in Fig. 10 and the activation energy obtained, 192



ig. 11. Plot of log Θ against inverse temperature for the different kaolins. The calculated activation energies are given with their 95 % confidence range.

cal/mole, can be expected to apply for kaolins with not more than 0—3 % f biminerals. However, it must be expected that the biminerals always present n the kaolin clays will give rise to minor changes of the Θ-values. The inetics are satisfactorily known after a single firing at constant temperature, nd the determination of the mullite percentage for the calculation of the onstant *a* in the equation (3) or after determination of the temperature at hich the 50 % mullite conversion time is one hour. In the latter case the equired temperature should be readily obtained from the temperature read om a differential thermal curve for the mullite peak after correction by an npirically determined factor dependent on the rate of temperature increase.

Application of Method A for the Al-Kaolins

The mica in the kaolins can be expected to affect the form of the time funcon when the mica content is as high as it is here, 7 and 14 %. A study of the me function for the Al-kaolins shows that mullite formation is somewhat ster at the beginning indicating that mullite is formed faster from the mica an from the kaolinite.

The kinetics for the mica and for the kaolinite can be separated starting om this point. Mullite formation from the mica is presumed to be largely omplete before the mullite formation from the kaolinite. Further the mica is esumed to correspond to a mullite contribution of 3 % for Al-kaolin 56 L d 6 % for the Al-kaolin 54.

Evaluation of the rate constants is shown in Tables 9 and 10. No values have een calculated for mullite percentages lower than 18 % because of the possible

Table 9. Calculation of the 50 % conversion time for Al-kaolin 56 L

Mullite content m %	$\frac{m_\infty - m}{m'_\infty}$	$\left(\frac{t}{\Theta}\right)$	1 175° C		1 150° C		1 125° C		1 100° C	
			t	Θ	t	Θ	t	Θ	t	Θ
18.0	70.0	0.48	0.15	0.312	0.46	0.96	1.98	4.13	9.10	19.0
23.0	60.0	0.72	0.23	0.319	0.75	1.04	3.25	4.52	14.3	19.9
28.0	50.0	1.02	0.31	0.304	1.00	0.98	4.80	4.71	20.5	20.1
33.0	40.0	1.46	0.40	0.274	1.30	0.89	6.70	4.58	27.0	18.5
38.0	30.0	2.16	0.58	0.269	1.72	0.80	8.80	4.07	36.0	16.7
43.0	20.0	3.14	0.76	0.242	2.35	0.75	11.4	3.63		
t in hrs Θ in hrs ..		Θ MV	0.287		0.90		4.27		18.8	
$m_\infty = 52.9$ % ...... $m'_\infty = 49.9$ %		$\left(\frac{1}{T}\right) .10^4$	6.906		7.027		7.153		7.283	

E = 223 kcal/mole. 95 % confidence range ± 34 kcal/mole.

Table 10. Calculation of the 50 % conversion time for Al-kaolin 54

Mullite content m %	$\frac{m_\infty - m}{m'_\infty}$	$\left(\frac{t}{\Theta}\right)$	1 125° C		1 100° C		1 075° C		1 050° C	
			t	Θ	t	Θ	t	Θ	t	Θ
18.8	70.0	0.48	0.47	0.98	1.53	3.19	9.00	18.7	38.0	79.2
23.1	60.0	0.72	0.77	1.07	2.50	3.47	15.7	21.8		
27.3	50.0	1.02	1.15	1.13	3.90	3.82	24.0	23.5		
31.6	40.0	1.46	1.67	1.14	5.85	4.01	34.0	23.3		
35.9	30.0	2.16	2.40	1.11	8.15	3.77	48.0	22.2		
40.1	20.0	3.14	3.43	1.09	11.7	3.73				
t in hrs Θ in hrs ..		Θ MV	1.09		3.67		21.9		79	
$m_\infty = 48.7$ % ...... $m'_\infty = 42.7$ %		$\left(\frac{1}{T}\right) .10^4$	7.153		7.283		7.418		7.559	

E = 215 kcal/mole. 95 % confidence range ± 48 kcal/mole

Table 11. Comparison of time necessary for 90 % mullite conversion

Temp. ° C	1 050	1 075	1 100	1 125	1 150	1 175	1 200	1 225
Hydrite PD 10				180	53	16	5.1	1.7
Al-kaolin 56 L			87	21	5.5	1.5		
Al-kaolin 54	430	96	22	5.6	1.5			

effect of the mica present. The activation energies have been calculated fron the temperature dependence of the time constants as 223 kcal/mole for Al kaolin and as 215 kcal/mole for Al-kaolin 54.

Table 11 shows a comparison of the time in hours required for 90 % mullit conversion for the different kaolins.

Application of Method B for the Hydrite PD 10

This treatment shows that the formation of mullite can be treated approximately as a first order reaction provided that the unprecipitated mullite is regarded as the driving force and that the mullite content is calculated not for the total system but for the reactive part of the system. It should be emphasized again that this treatment does not correspond to any reaction mechanism but merely permits a satisfactory expression of the kinetics.

If

$$c_m = \frac{(m_\infty - m)}{(100 - m - b)} \cdot 100 \tag{5}$$

$$-\frac{\mathrm{d}\,c_m}{\mathrm{d}t} = k \cdot c_m \tag{6}$$

where

b = the percentage of inactive minor constituents
c_m = the percentage of mullite in the reactive part of the system
k = a rate constant with the dimension of time^{-1}.

The limiting condition

$$c_m = \frac{m_\infty}{100 - b} \text{ for } t = 0 \text{ gives}$$

$$\ln\left(\frac{c_m\,(100 - b)}{m_\infty}\right) = -k \cdot t \tag{7}$$

In Fig. 12 log c_m is shown as a function of the time for Hydrite PD 10. As can be seen it fits straight lines rather well. The reaction rate constants k have been calculated from the slope of the temperature and the slope of this line gives the activation energy as 190 kcal/mole (Fig. 13).

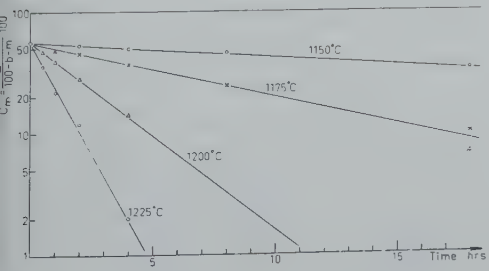


Fig. 12. Plot of log c_m against time at different temperatures for Hydrite PD 10.

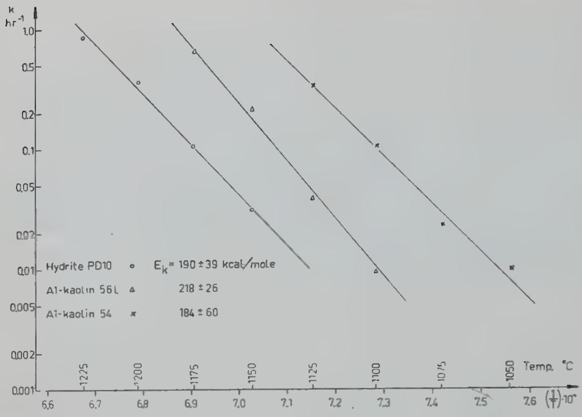


Fig. 13. Plot of log k against inverse temperature for the different kaolins. The calculated activation energies are given with their 95 % confidence range.

Application of Method B for the Al-Kaolins

For the mica-containing kaolins also the mullite formation in the kaolin can be given approximately as a first order reaction.

Log c_m is plotted again as a function of the time where c_m is given by the same expression as before but with the limiting condition

$$c_m = \frac{m_{\infty} - m_g}{100 - m_g - b} \cdot 100$$

$$t = 0$$

where m_g is the mullite percentage corresponding to the amount of mica present.

Figs. 14 and 13 give the time and temperature relationships for Al-kaolin 56 L. The linearity is satisfactory. The same is also found with the conditions of the Al-kaolin 54 which are given in Figs. 15 and 13. The activation energies were determined as 218 and 184 kcal/mole respectively.

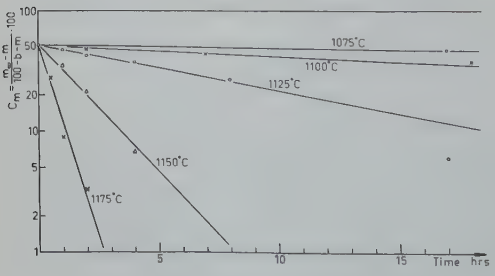


Fig. 14. Plot of log c_m against time at different temperatures for Al-kaolin 56 L.

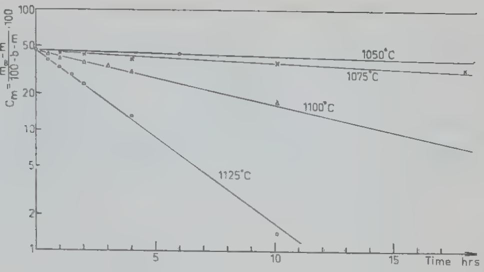


Fig. 15. Plot of log c_m against time at different temperatures for Al-kaolin 54.

Summary

Experimental data have been given for the rate of formation of mullite in three kaolins, one mica-free and two containing mica. These data show that the presence of mica increases the rate of formation of mullite in the kaolinite fraction. It is also shown that the studied mullite formation is no recrystallization and that before this mullite formation most of the available Al_2O_3 is present as γ-Al_2O_3. That means that the exothermic reaction at 950° C cannot be explained as a total or partial formation of a mullite phase.

Two different methods are presented for treating the kinetic course. The first and better method has a theoretical background and allows a simple and reliable treatment of the kinetics using an empirical time function and a characteristical time constant. The second method gives the kinetics approximately in terms of a first order reaction. The kinetic treatments have been applied to the mica-free kaolin as well as the two kaolins containing appreciable amounts of mica. Rate constants and activation energies have been calculated. The activation energies for the formation of mullite in the kaolinite fractions of different kaolin clays is about 200 kcal/mole.

Acknowledgment. The author wishes to thank Professor Dr. Otto Stelling, head of the Division of Applied Inorganic Chemistry, for his kind interest and advice, and *The State Council of Technical Research* in Sweden for its financial support of this work.

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Några drag ur Kalmarområdets berggrundsgeologi

Av

ERIK ÅHMAN

Abstract: The first part of this paper is a survey description of a window with rchaean quartzite and uraliteporphyrite exposed 2 km NE of Kalmar, the former ock belonging to the Vestervik series. In the second part is dealt with localities of uartzitic sandstone and grey "*kråksten*", belonging to the Lower Cambrian and situated bout 5 km NE of Kalmar.

Urbergsfönstret kring Skallöarna

Genom de sista decenniernas talrika brunnsborrningar har framkommit, att en inom Kalmarområdet föga blottade Kalmarsundssandstenen har en mäk- ighet varierande mellan 20 och 50 m. Ställvis är mäktigheten dock mindre, l. a. inom de områden, där dess underlag utgöres av till Västerviksserien hö- ande kvartsit. Denna har sålunda bildat höjder inom sandstenens avsättnings- mråde. Där har i vissa fall genom erosionen uppkommit fönster i sandstens- icket, och ett av dessa är beläget kring Skallöarna ca 2 km NO om Kvarnhol- nen i Kalmar stad. I detta fönster är på Norra Skallö blottat en kvartsit, vilken mnämnts tidigare av bl. a. MUNTHE (1902) och HÄGGFORS (1936). På de när- elägna Hammershögarna, se fig. 1, anstår en uralitporfyrit.

Kvartsiten, som är mycket homogen, är glasartad och mer eller mindre mörkt råröd. Endast på få ställen visar den antydan till skiktning strykande N 15° V ch stupande 60°—70° mot VSV. Varken inlagringar av ursprungligen lerigt aterial eller sprickfyllnader av karaktären sandstensgångar ha påträffats. Inom orra delen av den största blottningen är kvartsiten starkt breccierad i ett fler- l jämsides med varandra löpande, ungefär nord-sydliga stråk. De kantiga rottstyckena äro hopläkta av en mjölkvit kvarts, se fig. 2. Därvid ha uppkom- it vissa figurer, bl. a. en bildning i form av ett mantuakors på den nordöstra dan av hällen. I den vita kvartsen iakttages smärre kristallgrottor med otyd- gt utbildade kvartskristaller. Breccieringen har tidigare uppmärksammats av UNTHE (1902), som sätter den i samband med en horstbildning.

Mineralogiskt sett utgöres den grova kvartsiten av i huvudsak 2—3 mm stora divid av kvarts, vilka på grund av den ovannämnda tektoniseringen uppvisa markant undulös utsläckning. I kontakten mellan de sågtandade kvartsindi- den uppträder ofta smärre individ och aggregat av muskovit. Vidare före- ommer små korn av järnmalm tillsammans med sliror av limonit. Slutligen pträder liksom i Västervikskvartsiten mycket underordnat turmalin, vilket

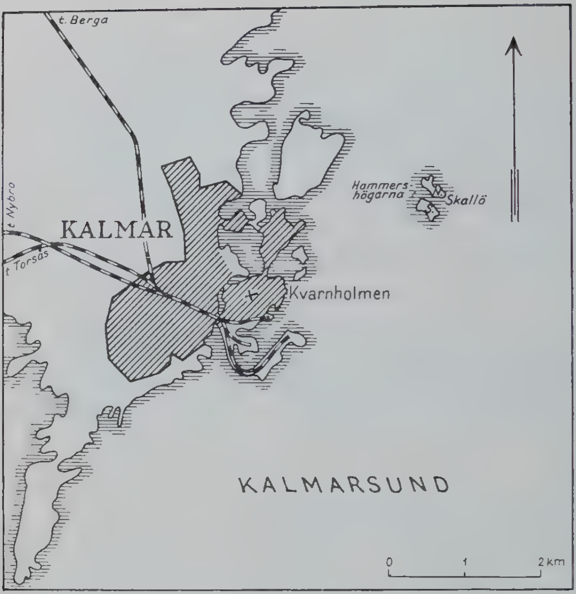

Fig. 1. Ungefär 2 km NO o Kvarnholmen i Kalmar sta ligga Skallöarna och Hammershögarna. — M. Ekman del. *About 2 km NE of Kvarnholme Kalmar town, are the Skallö- an Hammershögarna islands situated.* För spridning godkänd i Rike allmänna kartverk den 1 de 1958.

visar, att kvartsiten ursprungligen avsatts i havsvatten, vars borhalt fixerats turmalinen.

De låglänta och omedelbart V om Skallöarna belägna Hammershögarna uppbyggas av mycket stora block, vilka samtliga bestå av en svartgrå uralitporfyri Dess mineralogiska sammansättning karaktäriseras av 2—3 mm stora strökor av biotit, vilka äro rikligt genomvuxna av till matrix hörande plagioklasind vid, tillika med 1—2 mm stora strökorn av antydningsvis idiomorfa plagiokla individ. De sistnämnda äro samtliga från centrum och utåt så starkt sericiton vandlade, att tvillingslamelleringen utsuddats och deras anortithalt därför kunnat bestämmas.

Mellanmassan, som har ofitisk struktur, utgöres till ungefär hälften av e grågrönt hornblände i smärre individ, sammanvuxna med ungefär lika stor biotitindivid. Den andra hälften består av friska stavformade plagioklasindivi med andesitisk sammansättning, 45—50 % An (symmetriska utsläckningsmeto den). Mellanmassan karaktäriseras av en jämn fördelning av små runda magnetitkorn.

Uralitporfyritblocken, som uppbygga Hammershögarna, härstamma uppen barligen från en mycket bred gång. Bergarten, som här representerar den yng ta utvecklingsfasen inom urberget, genomsättes av ungefär 2 cm breda sprick gångar av en röd, salisk, medelkornig granit. Denna utgör en sekundär upp smältningsprodukt av en i närheten anstående röd Smålandsgranit. Enligt mun ligt meddelande av P. H. Lundegårdh äro uralitporfyritgångar vanliga ino urbergsterrängen V om Kalmarsundsstenen och synnerligen talrika i Nybr trakten.

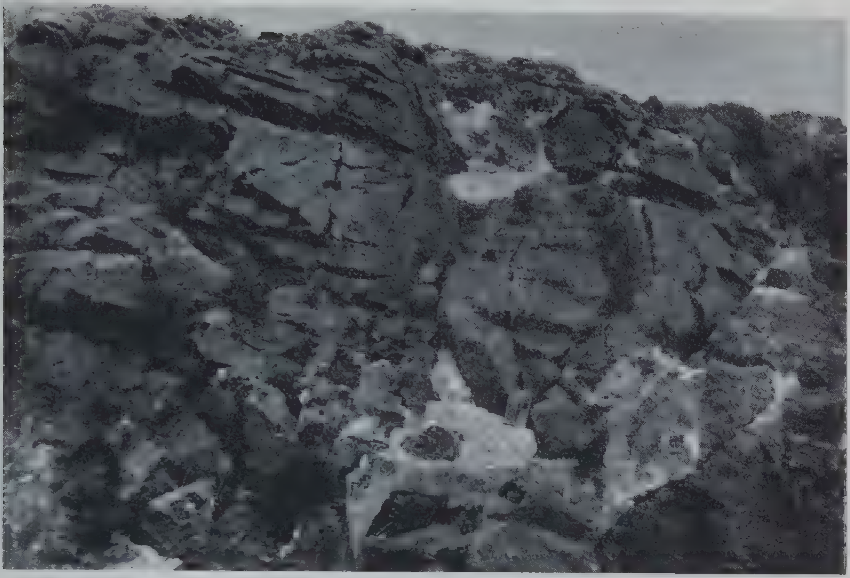

Fig. 2. Breccierad kvartsit hopläkt av vit kvarts. Stora hällen på nordspetsen av Norra Skallö. — Foto E. Åhman
Brecciated quartzite cemented by white quarts. The big outcrop on the nothern point of Norra Skallö.

Den ljusa sandstenen vid Smedby reningsverk

Av det geologiska material, som framkommit vid brunnsborrningarna i Kalmartrakten har tyvärr den allra största delen gått till spillo, då det ännu ej föreligger skyldighet för brunnsborrare att till ett centralt arkiv insända uppgifter om borrningens belägenhet och djup, de lösa lagringarnas mäktighet, arten av genomborrade bergarter etc. Större brunnsborrningsfirmor, t. ex. Svenska Diamantbergborrnings AB och AB Abevatten i Sundbyberg, ha tid efter annan låtit trycka förteckningar med uppgifter om utförda brunnar, dock med få data från Kalmartrakten.[1] Ej heller Sveriges geologiska undersöknings Brunnsarkiv redovisar något större antal borrbrunnar från Kalmar med närmaste omnejd.

Förf. har under de senaste åren insamlat uppgifter från brunnsborrningar och andra arbeten inom det aktuella området, vid vilka Kalmarsundssandstenen blivit påträffad i fast klyft. Av föreliggande data framgår, att inom Kalmar stads område påträffas den fasta berggrunden med några få undantag under ett 5—30 meter mäktigt täcke av lösa pålagringar samt att sandstenen i regel påträffas på 5—10 meters djup norr och söder om Kalmar. Inom f. d. Dörby och Hossmo kommuner, från vilka förf. har de flesta observationerna, har sandstenen vid flerfaldiga tillfällen påträffats under ännu tunnare täcken av kvartära avlagringar. Man får härav den uppfattningen, att berggrundsytan är av samma småkulliga natur som det nutida landskapet. I ett par fall påträffas sandstenen i anmärkningsvärt ytligt läge — på 1 meters djup och t. o. m. mindre.

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[1] Svenska Diamantbergborrnings AB arkiverar dock material från utförda borrningar.

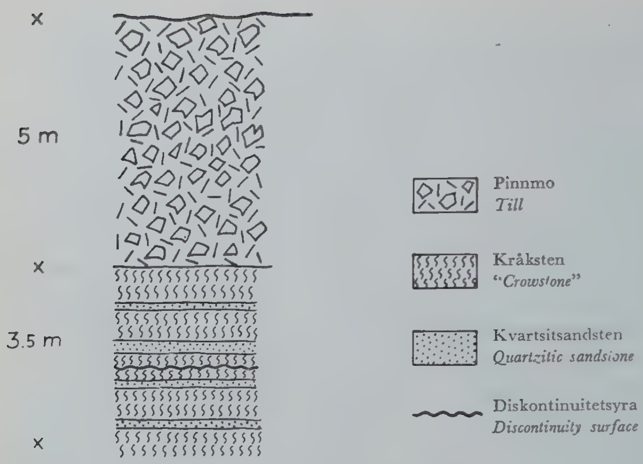

Fig. 3. Profil genom moränen och översta delen av Kalmarsundssandstenen vid Smedby Reningsverk, Rinkabyholm. Rekonstruktion efter arbetsledningens anvisningar. — M. Ekman del.
Profile through till and upper part of the Kalmarsund sandstone at Smedby reningsverk near Rinkabyholm. Reconstruction according to information from the work organisation.

Den är på dessa ställen avsevärt ytvittrad eller delvis t. o. m. genomvittrad. Vid sprängningar och borrningar av brunnar genom denna grunt liggande sandsten har man efter några meters avsänkning påträffat ett lager av finsand — av brunnsborrare benämnd »vesasand» — av varierande mäktighet och därunder ånyo sandsten. På grund av detta förhållande är man benägen antaga, att sandstenen lokalt föreligger i form av isskjutna skållor. Isskjutna skållor av sedimentära bergarter äro kända från flera lokaler i Sverige och ha beskrivits av skilda författare. Westergård m. fl. (1939) har beskrivit en isskjuten skålla av ortocerkalk på Limön utanför Gävle.

Ett ovanligt gynnsamt tillfälle till studium av sandstenen inom Kalmarområdet yppade sig våren 1956 i samband med anläggningsarbeten för rötkammare vid Smedby kommuns avloppsreningsverk, beläget 1,5 km ONO om Rinkabyholms järnvägsstation och något S om korsningen mellan riksväg 4 och Kalmar—Torsås järnväg. Fem meter under markytan, alltså på ordinärt djup, påträffades sandstenen, och i denna sprängdes sedan ett 3 ½ meter djupt schakt under delvis svåra förhållanden på grund av en riklig vattenföring genom några öppna slag i sandstenen. Vattenflödet uppskattades till 4 000 minutliter. Dessa arbeten kommo till förf:s kännedom på ett så framskridet stadium, att den blottade profilen vid mitt besök på platsen hunnit överbyggas. Densamma har dock efter arbetsledningens utsago rekonstruerats i fig. 3 och uppvisar grågrön »kråksten» av gängse typ med 4 stycken 5—10 cm mäktiga, gråvita kvartsitsandstensbankar. Diagenesen hos dessa har gått längre än i »kråkstenen». Ungefär i profilens mitt påträffades ett skikt med ojämn konfiguration, sannolikt markerande en diskontinuitet i sandstenen.

Kråkstenen

Kråkstenens petrologiska förhållanden med sin av maskar störda skiktning är välkända från skilda beskrivningar, varför de här förbigås. Uppträdandet av gråvita kvartsitsandstensbankar i bergarten har dock hittills endast uppmärk-

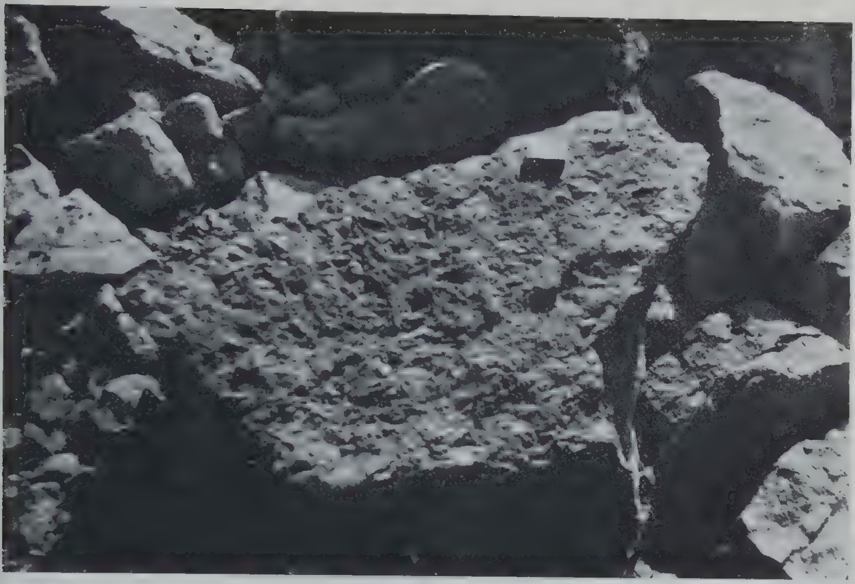

Fig. 4. Block av kråksten med frilagd diskontinuitetsyta. — Foto E. Åhman.
Blasted boulder of "kråksten" with exposed discontinuity surfase.

sammats av Hessland (1953) inom avsnittet 150—135.5 meter av den år 1948 upptagna kärnan från borrningen vid Böda Hamn på Öland.

Kvartsitsandstenen

Kvartsitsandstenen, vilken med tydliga kontakter är avgränsad mot kråkstenen, uppträder som ovan nämnts i 5—10 cm mäktiga bankar, vilka uppvisa en genom diagenesen något beslöjad skiktning med omkring mm-breda varv. I något fall har diskordantskiktning uppmärksammats. I bankarnas kontakter mot underlaget uppträda ofta 1—2 cm stora och någon mm tjocka lerlinser. Vidare uppmärksammas inneslutningar i form av ofta kantiga, små, gråvita till ljust grågröna lerfragment, vilka ej ha undergått diagenes, och som sällsyntheter dessutom små bollar och konkretioner av svavelkis. Sandstenen, som bevarat något av sin porositet, genomsättes av enstaka större sprickor, vilka som nämnts på sid. 484 uppvisa en riklig vattenföring. Sprickväggarna äro helt beklädda med druser av halvmm-stora kvartskristaller, hos vilka ytorna $\{10\bar{1}1\}$ och $01\bar{1}1\}$ äro tydligast utbildade. Anvuxna på kvartsdrusen uppträda i sin tur aggregat av halvmm-stora kuber, oktaedrar och genom kombination av dessa ormer utbildade svavelkiskristaller.

Kvartsitsandstenen består av dominerande kvarts i jämnstora individ med en diameter av 0.2—0.3 mm. Skiktningen markeras av ungefär halvmm-tjocka mellanskikt, uppbyggda av kvartsindivid med en diameter av endast 0.05—0.08 mm. Kvartsindividen uppvisa mycket tydliga tillväxter, som ha samma optiska rientering som de primära individen. Gränsen mellan primära individ och tillväxt framgår klart av sekundärt inneslutna partiklar på de primära kvartskornens ytor. Tillväxterna utfylla praktiskt taget alla ursprungliga hålrum mellan mineralkornen.

Accessoriskt uppträder i kvartsitsandstenen limonit, turmalin, kalcit, mikroklin och muskovit.

I den av HESSLAND (1953) beskrivna delen av kärnan från Böda Hamnsborrningen uppmärksammas på en nivå av 15—25 meter ovan urberget några endast ett par dm mäktiga bäddar av ljus, nästan kvartsitisk sandsten. Den underkambriska sandstenen uppvisar i Kalmartrakten i de fåtal fall, då den blivit genomborrad, en mäktighet av omkring 20 m, varför man har all anledning antaga, att de ovan beskrivna kvartsitsandstensbankarna kunna korreleras med de av HESSLAND beskrivna. Kvartsitsandstenen är sannolikt identisk med den av MUNTHE (1902, sid. 23) omnämnda, i block N om Kalmar påträffade vita sandstenen med sockerlikt utseende.

Diskontinuitetsytan

I kråkstenen uppträder, som ovan omnämnts, en diskontinuitetsyta. Dess exakta läge i lagerföljden har ej kunnat fastställas, men vid mitt besök på platsen visade åtskilliga block ytan ifråga (se fig. 4). Den ljust grågröna och ojämna ytan är täckt av oregelbundna halvcm-höga oftast stavliknande vallar och valkar uppbyggda dels av grå lerrik och dels av vit lerfri sandsten. Dessa äro överdragna av en tunn lerhinna. Som redan nämnts karaktäriseras kråkstenen av störd skiktning, ett resultat av maskars arbeten i det primära sedimentet, och den ovannämnda diskontinuitetsytan kan kanske ha uppkommit på liknande sätt. Gynnsamma omständigheter ha uppenbarligen bidragit till att strukturerna bevarats. LANNERBRO (1954) beskriver snarlika strukturer från Dalarnas jotniska sandsten, vilka dock ej torde ha organiskt ursprung (jfr SCHINDEWOLF 1956).

Den grå kråkstenen i Dörbylundsområdet

Vid anläggning sommaren 1958 av en ledningsbrunn inom Dörbylundsområdet ca 5 km VSV om Kalmar, ungefär 200 m före skärningen mellan riksväg 4 och Kalmar—Torsås järnväg från Kalmar räknat, och således endast ca 400 m från den ovannämnda lokalen vid Smedby reningsverk, stötte man oförmodat på ett anstående av ovittrad kambrisk sandsten på ett djup av 3 ½ meter under markytan. Arbetena, som krävde en nedsänkning 1 ½ m i berget, besvärades även här av ett starkt vattenflöde om ca 2 000 minutliter.

De översta decimetrarna av den därvid blottade profilen utgöres av en som kråksten utbildad vit- och brunfläckig sandsten, som i sin basala del uppvisar enstaka smärre fragment av underlagrande grågrön kråksten, tydande på att den avsatts i ett strandnära läge och tidvis varit utsatt för nedbrytning. Kontakten mellan kråkstensvarianterna är skarp på grund av färgkontrasten.

Den underliggande glaukonitsandstenen är vackert grågrön och merendels massformig med undantag av här och var uppträdande otydliga utbildningar som kråksten. Bankar av vit kvartsitsandsten uppmärksammades ej i profilen. Om de äro utbildade här böra de finnas på en djupare nivå. En närmare undersökning av den grå kråkstenen ger vid handen, att den har ringa halt av glaukonit och att dess cement till stor del utgöres av karbonat. I cementet uppträder även smärre mängder av limonit. I denna kråksten förekommer ofta ansamlingar av gråbruna lerlinser, vilka vid en mikroskopisk undersökning visa sig bestå av ett flertal kalcitindivid, som äro starkt förorenade och uppskattningsvis till 70—80 % innesluta lera och små merendels skarpkantade kvartsfragment.

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HELGE G. BACKLUND

1878—1958

För något mindre än ett år sedan — den 29 januari 1958 — gick Helge Götrik Backlund ur tiden. Därmed miste vårt land en av sina kunnigaste, färgstarkaste och idérikaste petrologer genom tiderna.

Helge Backlund blev redan från födseln kosmopolit. Han såg dagens ljus den 3 september 1878 i Dorpat. Hans föräldrar var observatorn, sedermera direktören för Pulkovoobservatoriet Oskar Backlund och Ulrika Widebeck.

Sin uppfostran fick Helge Backlund huvudsakligen i Ryssland — ett Ryssland utan järnridå gästat av många utländska forskare. Flera av dessa sökte sig till Pulkovo utanför S:t Petersburg och blev gäster i föräldrahemmet. En kulturell vidsyn och en naturlig säkerhet i uppträdandet blev självklara följder av den unge Helge Backlunds liv i denna rika miljö. Intresset för naturvetenskap vaknade också tidigt, och skarpblick parad med god fysik lämpade sig väl för hans ämnesval — geologin. Till den av von Schmidt ur sibiriska tundran framgrävda mammuten återkom han gärna på sin ålders dagar. Jättedjuret och expeditionen, som lett till dess förevisande i S:t Petersburg, tilltalade alldeles uppenbart hans fantasi starkt och blev i hög grad bestämmande för hans yrkesval.

Redan 1899 kom han själv att deltaga i en forskningsresa, första etappen i den av Tjernysjev ledda, svensk-ryska gradmätningsexpeditionen till Spetsbergen (1899—1901). Hans intresse fångades där av de mäktiga platåbasalterna. Under 1905 utförde han geologiska undersökningar och astronomiska ortsbestämningar mellan floderna Jenisej och Anabar, delvis under mycket svåra förhållanden.

1906 for Helge Backlund till Wien för studier och forskningar hos Becke. De Beckeska arbetsmetoderna blev av största betydelse för hans vetenskapliga produktion under de följande åren. Man lägger från denna tid märke till 'Über die Olivingruppe' (1909) och en rad uppsatser över Spetsbergsbasalterna.

1909 började Helge Backlund regionala undersökningar i Uralbergskedjans nordligaste delar samt trakten öster därom, särskilt Taimyrhalvön. På grund av världskriget 1914—1918 och den därav följande, stora inre oron i Ryssland kom publiceringen av Backlunds redan vid årsskiftet 1913/14 färdiga Taimyravhandling att fördröjas. 1917 trycktes en förkortad version i GFF, och först 1929 utkom den kompletta avhandlingen. I och med dessa Backlunds forskningar samt genom undersökningar av O. Holtedahl blev det uppenbart, att rester av en variskisk bergskedja finns norr intill det sibiriska urbergsblocket. Denna bergskedja ansluter sig till Ural. Bland andra resultat av Backlunds arbeten i nordligaste Sibirien märkes 'On the Arctic basalt plateau' (1921).

Helge Backlunds reslust fick en stöt i ny riktning vid geologkongressen i Stockholm 1910. Han träffade där chefen för Argentinas geologiska undersökning och förordnades 1912 som resultat av detta möte till statsgeolog för

1878—1958

ett år i det sydamerikanska landet. Dessförinnan hade han 1908 utsetts till kustos vid Vetenskapsakademiens i S:t Petersburg geologiska museum, där han 1912 blev chefskustos.

I Argentina bedrev Backlund omfattande forskningar i Anderna. En del av de vunna resultaten publicerade han 1923 i monografin 'Der magmatische Anteil der Cordillera von Süd-Mendoza'. Han betonar i denna vulkanismens periodiska uppträdande i den andina geosynklinalen.

Ryska revolutionen drog för Backlunds del med sig stora svårigheter. Han miste sin befattning som chefskustos och måste fly under dramatiska omständigheter. 1918 utnämndes han till professor vid Åbo akademi och byggde upp den nyinrättade geologiska institutionen till ett förstklassigt forskningscentrum, där bl. a. för första gången i Skandinavien undervisning i universalbordsmetodik gavs.

Under somrarna ledde han tillsammans med Quensel en berggrundskartering av Skanderna i södra Lappland (Västerbottens län). Arbetet ingick i SGU:s program och en detaljrik karta i skala 1: 200 000 trycktes 1929. Någon beskrivning utkom tyvärr aldrig.

1922 sökte Backlund den genom A. G. Högboms pensionering ledigblivna professuren i geologi med mineralogi vid Uppsala universitet. Sedan Geijer återtagit sin ansökan, kvarstod Backlund och G. Frödin som huvudkonkurrenter. Kampen mellan de båda blev lång och hård. Först 1924 utnämndes Backlund. Med sin vidsträckta instrumentella och metodologiska erfarenhet lyfte han upp den blygsamt utrustade institutionen i Kuggis till en för sin tid ur apparatsynpunkt mycket hög standard. Särskilt intresse ägnade han här liksom i Åbo åt de viktiga universalborden. Mineralsamlingen ordnades också enligt moderna principer.

Somrarna 1929 och 1930 följde Helge Backlund med Lauge Koch till Grönland. Här återfann han migmatitmotivet från Sederholms Sydfinland i de underbart väl blottade hällarna och bergen. Transformistiska tankegångar blev för honom allt mer naturliga. När så den gamle Sederholms unge, snillrike och entusiastiske medarbetare Eugen Wegmann började blåsa friska fläktar över geosynklinalutvecklingarna och migmatitiseringsförloppen både i Fennoskandia och på Grönland var det naturligt, att Backlund blev hans vapenbroder.

Trots hårt motstånd växte transformismens inflytande. Backlunds föreläsningar blev allt mer fascinerande med sina djärva utblickar över det gamla men ändå evigt unga forskningsfältet granit—gnejs. Han tröttnade aldrig på att betona kravet på konstant volym vid de flesta av orogenernas kristallinbergartsbildningar. Detta förde med sig antagandet av ombildningar av äldre bergarter genom jonutbyten i motsats till den tidigare i vårt land förhärskande hypotesen om nykristallisationer ur mer eller mindre starkt differentierande magmaintrusioner. Så kom då äntligen svensk petrologi i handgriplig kontakt med de transformistiska principer, som i Frankrike börjat taga form redan i mitten av förra seklet.

I geosynklinalutvecklingarna blev för Backlund blott basisk magmaaktivit kvar, medan såväl de primorogena som de serorogena (syn- resp. senkine-atiska) graniterna tolkades som sekundära. Även grönstenar tilläts ha icke-agmatiskt ursprung. Sålunda kunde ur kalkrika sediment anortitbetonad ıbbro bildas och ur dolomit peridotitiska bergarter.

I flera avhandlingar kämpade Backlund för transformismens idé och konse-venser. Särskilt beaktade har 'Der Magmaaufstieg in Faltengebirge' (1936),)ie Umgrenzung der Svekofenniden' (1937) och den sammanfattande 'Ein-icke in das geologische Geschehen des Präkambriums' (1943) liksom även 'he granitisation problem' (1953) blivit.

Stor uppståndelse väckte på sin tid 'The problems of the rapakivi granites' 938), där Backlund tolkade den lättvittrande porfyrgraniten som granitiserad tnisk sandsten. En häftig debatt mellan Backlund och von Eckermann blev det ırmaste resultatet av denna skrift. Först under den allra senaste tiden, när ra-ıkivigranitens ålder bestämts till omkring 1 500 milj. år, har emellertid berg-rtens genes blivit skönjbar — kan den höga åldern icke bero på att det ål-ersbestämda materialet i oomvandlat skick ärvts från en bergart, ur vilken ıpakivigraniten direkt eller med ett sediment som mellanled bildats genom ranitisering? Dock måste mobilisering av det granitiserande materialet här ksom i många andra fall ha haft långt större betydelse än Backlund medgivit.

Invändningar av denna art förringar icke värdet av Backlunds insats i kam-en för en transformistisk syn på vår kristallina berggrund. Att gnyet och va-enskramlet från tvivlarnas skara kommit honom att bli *in-situ*-granitisör till vermått är icke mer än mänskligt. Hans åsikter har också utgjort en omistlig llgång för den petrologiska diskussionen, även i de fall då de varit extrema.

Backlund var en god lärare. Hans litteraturkännedom hade så stor vidd, att even i honom såg en levande uppslagsbok. Hans praktiska erfarenhet av de ıest skilda geologiska problem och arbetsobjekt kom honom väl till pass både nder föreläsningar (Backlunds manus var små eller helt obefintliga) och när et gällde att hjälpa unga uppsatsskrivare till rätta. Hans metodologiska kun-kaper i förening med hans underfundiga humor gjorde mikroskopkurserna ll högtidsstunder.

Backlund inplantade i eleverna förmågan att behandla det vetenskapliga ıaterialet utförligt och med iakttagande av vidast möjliga aspekter. Utan ıot accepterade han även motsägelser mot sin egen tro. Så växte licentiat-rbetena i en del fall till doktorsavhandlingsformat, men eleverna lärde sig ımtidigt uttrycka sina tankar i skrift.

Åtskilliga hedersbevisningar kom Backlund till del under senare delen av ans liv. Förutom kallelser till ledamotskap i ett flertal in- och utländska lär-a samfund må nämnas hedersdoktorat i Uppsala 1927 och Wien 1940. 1943 llägnades Backlund samlingshäftet 2—6 av Geologische Rundschau på ini-ativ av Hans Cloos. Här upptages större delen av sidorna 72—74 av en så tt jag kunnat bedöma fullständig förteckning över Backlunds tryckta arbeten o. m. 1942, ett med tanke på de starkt spridda publiceringsorterna synner-gen värdefullt aktstycke.

Per H. Lundegårdh

PAUL W. THOMSON

AN ESTONIAN NATURALIST

1891—1957

It was with sorrow and regret that I received the news. Doctor Paul W Thomson had passed away at Bonn, Germany, on the 13th of December, 1957 at the age of sixty-six. He was one of the undoubted pioneers in palynology the science of pollen grains and spores, and a keen naturalist in the tru meaning of this word. Paul W. Thomson was born in Tallinn, Estonia, on th 22nd of December in 1891 and both his personal life and his scientific wor reflect, perhaps somewhat naturally, the troubled times, shadowed by war and occupation of Estonia, as well as the many years when everything seeme so bright and promising. He served in the Armed Forces of Estonia durin the War of Independence (1918—1920) and held the military rank of Cap tain. In 1920—21 he gave lectures on explosives at the Estonian War Academ since he in his previous professional training had specialized in chemistry an the natural sciences. From 1923 until the occupation of Estonia in 1940 h held a position as lecturer in chemistry and botany at the Agricultural Schoo and the Experimental Station at Tooma. He received his Doctors Degree i 1927 at the University of Riga, Latvia, and later lectured at the Universit of Tartu in Estonia. Furthermore, because of his dedication to natural scienc he found time to spare for teaching science at highschool. From 1928 onwar he has been a member of the Geological Society of Stockholm.

The list of his publications speaks for itself and yet I cannot claim that have been able to include all titles.

Professor Thomson's palynological studies in Estonia served a twofol purpose. They added to the fundamental knowledge of the postglacial climati changes as interpreted from the forest history of Estonia and his studie formed the necessary background for studies of the recent vegetation. Despit of many difficulties he managed to solve the problems with his remarkabl energy, ambition and patience. Besides the palynological study of the pos glacial deposits he contributed significantly in other fields of the natura sciences, too. His studies of the late-glacial and interglacial deposits and h study of Devonian rocks deserve special mention. During later years his studie of Tertiary lignites in Germany, their origin and his fundamental study o plant microfossils in these deposits became well known and recognized amon his colleagues.

His untimely death is a serious loss to palynology and to his friends wh will always remember him as a pioneer who blazed the trail for a new scienc

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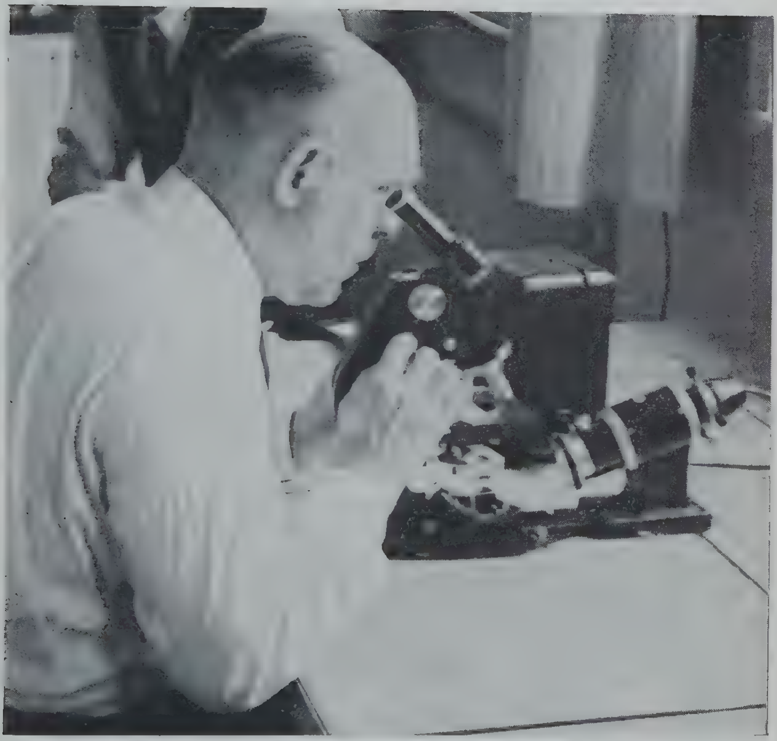

PAUL W. THOMSON
1891—1957

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Notis

Regarding the Definition of π

By

MAURITS LINDSTRÖM

> "The question is", said Alice,
> "whether you *can* make words mean different things".
> "The questions is", said Humpty Dumpty,
> "which is to be master — that's all".
>
> LEWIS CARROLL

In the preceding issue of this periodical, HANS J. KOARK (1958) criticized me and P.-G. HJERN jointly for having used the term π in a sense contrary to what is the general use in Gefügekunde. To some, this might seem a trifling matter. However, KOARK is known as an advocate of the fixity of nomenclature in his branch of science, and for this I keep him in high esteem, as I am of much the same mind. KOARK refers to SANDER (1942 & 1948) as the authority of Gefüge nomenclature. With this, too, I am in entire agreement. It would be well if SANDER 1948 were acknowledged as the ultimate authority in matters of Gefüge terminology. As KOARK also is aware, I have indeed attempted to follow SANDER in my definition of π. The disagreement concerns the interpretation of what SANDER has written.

HJERN (1958) and I (LINDSTRÖM 1957, 1958) define π as the normal of s-surfaces (non-genetic term, mainly for bedding-planes, foliation, and schistosity). KOARK mentions π only as die Kreiskonstante, and states that it is generally used to characterize tautozonal s-surface orientations, mainly as part of compound nouns like π-Kreis, π-Achse, and π-Pol. It shall not be questioned now whether this definition of π is useful or not; only whether KOARK is right or not in assigning it to SANDER 1948.

KOARK's reasoning is founded on the following sentence that can be found in SANDER 1948 (p. 139), "Im betrachteten Falle ist dieser s-Pol-Kreis als π-Kreis bezeichnet, sein Lot als π-Achse, der Ort von π in der Projektion als π-Pol." The s-Pol is the projection point of the normal of an s-surface, hence also the representation of the s-surface normal in the diagram. Now, the sentence quoted above tells us that s-Pol-Kreis = π-Kreis. It seems logical to infer that s-Pol = π, which is practically, though of course not logically, the same as to say that π is the s-normal, as the s-Pol is our representation of the s-normal. The only other definition of π that can be extracted from SANDER's sentence is "the something which has the π-Pol as its locus". Now, a pole is a point, and what has the point as its locus must be the point itself, hence π = π-Pol. To define the π-Pol, SANDER refers to fig. 41, p. 138. In this figure, π occurs in one place, and is indicated thus, "s-Pole (π)". It is hard to escape the impression that s-pole and π in this case are placed as synonyms.

SANDER mentions π as the s-surface normal, and its projection point, the s-pole, on two more places in his 1948 work. One of them is a sentence quoted by KOARK and occurring on p. 132 in SANDER 1948. It is possible that the construction of SANDER's phrase in this case is unintentional, as maintained by KOARK, but the writing certainly stands there. The other place is on p. 138, ninth line from above.

Is it not excusable that one regards the definition π = s-normal (and the representation of the s-normal) as codified?

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Anmälanden och kritiker

Paul Woldstedt: Das Eiszeitalter. Grundlinien einer Geologie des Quartärs. Zweiter Band. Europa, Vorderasien und Nordafrika im Eiszeitalter. Zweite neu bearbeitete Auflage. Ferdinand Enke Verlag, Stuttgar 1958. VII + 438 sid., 125 textfig., 1 tavla, 24 tab. Pris hft 65: — DM inb. 69: — DM.

Andra upplagan av Woldstedts välkända lärobok var från början avsedd att omfatt två band, vilket redan det innebar en utökning till det dubbla sidantalet, jämfört me första upplagan. Kännedomen om kvartärtidens geologi har emellertid på sistone ökat i en sådan takt, att redan i denna upplaga endast en del av den regionala kvartärgeologien rymts i det nu föreliggande band 2. Detta omfattar således endast Europa oc de utomeuropeiska delarna av Medelhavsområdet. Av någon anledning har dock int Island fått vara med, vilket man annars tycker skulle varit naturligt, i synnerhet som även detta medtagits i bokens fig. 1 — översikt över det nordeuropeiska nedisningsområdet.

I band 1 märktes en betydande omarbetning, men i band 2 har denna varit änn mer genomgripande. Endast ställvis känner man igen rester av den gamla dispositio nen och även i dessa partier är det tydligt att en i stort sett fullständig nybearbetning gjorts. Betydande delar av boken, särskilt kapitlen om Medelhavsländerna, är hel nytillkomna. Det är ingen överdrift att säga att band 2 utgör en helt ny lärobok.

Minst genomgripande är kanske förändringarna i de första kapitlen, som behandla det nordeuropeiska nedisningsområdet i främst Tyskland och Danmark. Vad beträffa övriga kapitel, som berör detta nedisningsområde, vill det synas som om författaren ganska väl fått med även forskningens senaste rön. De verkligt revolutionerande förändringarna i boken finner man emellertid i de kapitel, som berör områdena utanfö de nordeuropeiska och alpina nedisningarna. Dessa kapitel är alltså nyskrivna och man får ett överväldigande intryck av kvartärgeologiens framsteg i dessa trakter, främs kanske i Italien. Urvalet i det stora materialet har säkert ej varit det lättaste och ka givetvis alltid diskuteras. Det förefaller dock som om det vore väl avvägt och som om allt det väsentligaste kommit med. I varje fall utgör boken en förträfflig inkörspo för den som närmare vill lära känna Sydeuropas kvartärgeologi.

Det ligger väl i verkets natur, att var och en kan hitta brister i just det område ha själv särskilt behärskar. Sålunda är det nog ingen svårighet för en svensk kvartärgeolog att göra anmärkningar mot det avsnitt, som behandlar sen- och postglacialtiden Skandinavien. Att här ge sig på en sådan detaljgranskning skulle emellertid ej gör boken rättvisa. Dess syfte är f. ö. knappast att ge en uttömmande skildring av de behandlade områdena utan endast en allmän översikt. Ett par punkter må räcka för a exemplifiera dylika anmärkningar: Skildringen av nivåförändringarna följer kansk väl mycket Sauramo. Visserligen nämns i korthet att t. ex. hinge-lines är omdiskuterad men något vidare om dessa motsatta uppfattningar får man ej veta. Vidare är det något egendomligt, att i fråga om de intressanta submoräna sedimenten i Centraljämtland endast hänvisas till ett muntligt meddelande. Något av den ej obetydliga litteraturen i ämnet borde nog fått vara med här.

Om den nordiska litteraturen föreföll något förbisedd i band 1 så gäller detta — egendomligt nog — än mer i band 2. De skandinaviska bidragen till litteraturförteckningen är lätt räknade, och man frågar sig nog, om urvalet där gjorts lika omsorgsful som i fråga om t. ex. den sydeuropeiska litteraturen. I någon mån sammanhänger d dock kanske med att den litteratur, som upptagits i band 1, ej upprepas i band 2 —

ett förfarande som man kanske i viss mån kan ha förståelse för, men som icke desto mindre ej är helt praktiskt för den läsare, som inte råkar ha båda banden till hands.

Illustrationerna är med få undantag goda och väl valda. Tyvärr är de ibland placerade så att texten läses upp och ned, ett fel som dock är blott alltför vanligt i den mesta litteratur. Ett avgjort plus för boken är tabellerna, med vars hjälp man kan få en uppfattning om de nu allt talrikare lokalbenämnda avlagringarnas stratigrafiska ställning.

Trots att det sista bandet ännu ej utkommit har man nog nu fått ett helhetsintryck av verket. Detta, som nästan genomgående är mycket positivt, innebär närmast, att verket är oumbärligt för den som vill skaffa sig en allmän uppfattning om utländsk kvartärgeologi, d. v. s. såsom lärobok. Genom utförligt register och redig uppställning lämpar den sig vidare utmärkt såsom uppslagsbok. Mindre lämplig är den endast då det gäller det egna landet. Där måste nog den inhemska litteraturen tillgripas.

Jan Lundqvist

A. Winkler-Hermaden: Geologisches Kräftespiel und Landformung. Grundsätzliche Erkenntnisse zur Frage junger Gebirgsbildung und Landformung. 822 Seiten. 120 Textabbildungen und 5 Tafeln. Wien 1957. Pris inb. DM 95: —.

I detta storartade verk, som tillägnats framlidne Albrecht Penck, framlägger författaren en sammanfattning av sitt livsarbete. Huvudmål för detta har varit undersökningen av de geologiska krafternas lagbundna verkningar under Alpernas tertiära utveckling och speciellt de verksamma geologiska faktorerna vid sedimentationsförloppen, tektogenesen och vulkanismen, samt deras relationer till de formbildande morfologiska krafterna. Arbetsområdet omfattar sålunda ett speciellt och hittills något försummat kapitel i översiktliga framställningar av Alpernas geologi, trots att det är av så stor betydelse för orogenesforskningen. Med detta bidrag har man fått ytterligare ett vederläggande av de påståenden, som vill göra gällande, att de alpingeologiska undersökningarna har stagnerat under de senaste decennierna.[1] Vederläggandet får särskild vikt därigenom, att föreliggande arbete icke är ett på avstånd tillkommet skrivbordsalster utan bygger på författarens under mer än 40 år utförda studier av petrografisk, stratigrafisk, tektonisk och morfologisk karaktär med ett 80-tal specialarbeten som underlag samt på ett intensivt litteraturstudium av ca 2 500 för ämnet aktuella arbeten.

För ovannämnda frågeställningar förutsättes ett säkert stratigrafiskt underlag för Alpernas berörda områden, deras randtrakter, samt angränsande mediterrana regioner och delar av Östeuropa. Det är främst tidsavsnittet från övre miocen (sarmat) till kvartär som med stor inlevelse diskuteras (ca 300 sidor) och det ställer höga krav på den i den alpina, mediterrana och östeuropeiska tertiärstratigrafien föga insatte läsaren. Här framhålles bl. a. ännu bestående oklarheter angående gränsdragningen mellan oligocen och miocen (aquitan), gammal- och ungmediterran och speciellt åtskillnaden av helvet och torton, miocen och pliocen i mediterranområdet, pliocen och kvartär, samt den stratigrafiska parallelliseringen av den pannoniska och den euxiniska utvecklingen. Utredningen syftar till att antingen uppnå godtagbara lösningar eller att precisera de divergerande ståndpunkterna.

Frånsett de divergerande åsikterna om uppkomstsättet och den regionala uppdelningen av de tertiära veckningszonerna och deras överskjutningstäcken samt fjällkedjeveckningens mekaniska problem har författaren ävenledes upptagit till behandling andra frågor av tektonisk natur, som bruka tolkas på olika sätt. Hit hör frågan om de tertiära veckningsfasernas antal, deras relativa längd och regionala spridning, problemet om orogenesens kontinuitet eller diskontinuitet; vidare frågan om de förekommande brottstrukturerna (enligt Stille) kan tillordnas de orogena faserna, eller om man måste räkna med epirogenetiska rörelser som orsak. Dessutom har upptagits till behandling spörsmålet huruvida Stilles »Gesetz der Hochfaltung» har allmän giltighet och den mycket spridda uppfattningen, att de yngre bergskedjornas höjningsrörelser huvudsakligen har skett postorogent. Vidare behandlas relationerna mellan de yngre veckningszonerna och angränsande områden med germanotyp tektonik.

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[1] Värderingen av s. k. vetenskapliga framsteg överskuggas tyvärr icke sällan av referenternas personliga åskådningar.

Sambandet mellan vulkanism och tektonik diskuteras endast med hänsyn till de unga eruptivmassornas uppträdande inom SÖ-Alperna och vid Balaton-sjön i västra Ungern. En mer ingående undersökning av hithörande spörsmål anses enligt författaren endast möjlig, om man dryftar dem i samband med den samtida vulkanismen inom Karpaterna (»innerkarpathischer Gürtel»), på Balkan och inom Appeninområdet.

De sedimentologiska frågeställningarna lägger vikt vid relationerna mellan sedimentation och tektonik. Det som här intresserar författaren särskilt är särskiljandet av orogen och epirogen sedimentation inom det sydväst-alpina avlagringsområdet, samt den cykliska sedimentationen (»Grosszyklen») med dess relation till tektoniken och slutligen inflytandet av eustatiska havsytevariationer på de regionala sedimentationsprocesserna.

Som redan bokens titel antytt är en av dess huvuduppgifter att utröna de kronologiska och genetiska relationerna mellan tektonik och morfogenes. Av behandlade och enligt Winkler-Hermaden fortfarande öppna frågor märks Davis »morfologiska cykel», med bl. a. problemet om de tektoniska rörelsernas inverkan på den samtida morfogenesen, samt de differentierade klimatiska inflytandena på den morfologiska utvecklingen av tertiär-kvartära landskap. Vidare förekommer en kritisk granskning av de geologisk-tektoniska förutsättningarna för utbildningen och den regionala utbredningen av s. k. »Rumpfflächen» samt Piedmonttrapporna inom yngre orogenområden. De stora meningsskiljaktigheter som råda, när det gäller dateringen av de morfologiska utvecklingsfaserna, belysas ingående; i vissa avseenden lämnas klargörande besked. Härvid påpekas bl. a., att ordnandet av bestämda geomorfologiska utvecklingstillstånd till hela längden av en geologisk »Stufe» eller t. o. m. en geologisk formation i de flesta fall är obefogat. Beteckningar som gammaltertiärt peneplan, miocent peneplan, osv. ger en oklar och felaktig bild av bildningens långvarighet, som vanligtvis utgör endast bråkdelar av den geologiska period, vars namn kommit till användning. (Detta gäller även för peneplan-benämningar i äldre orogenen.)

Det är självfallet omöjligt att inom denna ram ge ens en något så när rättvis bild av de ca 750 innehållsrika sidorna. Sålunda skall i fortsättningen endast nämnas några av författarens väsentliga arbetsresultat. Det kan väl förmodas, att de alpin-stratigrafiska frågorna ej har samma intresse för de skandinaviska länderna, som de mer principiella resultaten av tektonisk-orogenetisk och geomorfogenetisk karaktär.

Vid diskussionen av de tektonisk-orogenetiska förhållandena kommer Winkler-Hermaden bl. a. till den slutsatsen, att förekommande äkta brottbildningar tillhör en över lång tid fortgående utveckling och ej kan inordnas i Stilles fasbundna orogencykel. Representerande en form av s. k. tensionstektonik skiljer de sig från täckenbildningar, veckningar, germanotypa brottveckningar, o. d. — den s. k. kompressionstektoniken, som visar en utpräglad faskaraktär.

Vidare påvisas betydande epirogenetiska sänkningar och i samband med dessa förekommande »Verschüttungen», som under ungtertiär tid flera gånger har träffat hela Alpområdet, t. o. m. fram till pliocen, där de avbröts av den där redan tydliga höjningsutvecklingen. Dessa epirogena höjningar, med uppvälvningar som följd, skedde i aser och anses förorsakade av isostatiska rörelser eller underströmningar på djupet. Långvariga och inom ungtertiär tid talrikt förekommande skeden av utpräglad tektonisk inaktivitet anses uppträda omedelbart före eller efter tider karakteriserade av angentiell tektonisk verksamhet. Till dessa skeden knytas uppkomsten av markerade abrasionsterrasser och peneplanbildningar.

Alpernas kretaceisk-tertiära utveckling (»alpidischer Grosszyklus») uppdelas på grund av omfattande transgressioner i övre kritan (maastricht) i en kretaceisk och en ertiär evolution. Orogenesens höjdpunkter med bildningar av överskjutningstäcken knytas till mitten av krit-tiden och till början av tertiär-tiden. Från och med miocen är ett avtagande av de orogena rörelserna påtagligt. Den tertiära orogena evolutionen ägnas en ingående analys med bl. a. en uppdelning i fem huvudcykler (laramisk, pyreneisk, savisk, steirisk, yngstalpidisk). Varje huvudcykel består av orogena, epirogenetiska och tektoniskt inaktiva stadier. Den sista huvudcykeln (yngstalpidisk: från sarmat ill nutiden) uppdelas t. ex. ytterligare i sju delskeden, varvid de orogena rörelserna underindelas i olika veckningsstötar (»Faltungsstösse»).

Alla i dagens relief förefintliga morfologiska formelement kan inom Östalperna inordnas i den sista cykeln, d. v. s. att de är icke äldre än sarmat. Hit räknas som äldsta enheter de inom centrala delar över 3 000 m höjd belägna peneplanrelikterna (»Inselberge»). De vidsträckta och iögonfallande höjdytorna på något lägre nivå anses ha illkommit under eller strax efter pliocen tid.

Under ungtertiär tid bildade Alpområdet aldrig en slätt utan ett kuperat landskap, ofta med »Mittelgebirgs»-karaktär. Alpernas morfologiska utveckling under tertiärtidens fem orogena huvudcykler visade enligt stratigrafiska och sedimentologiska kriterier upprepade evolutioner med reliefbildning under och efter höjningsrörelserna och därtill anslutande utjämningstendenser intill nästa höjningsepoks början. De tertiära Alpernas relief har således haft fem reliefenergetiska höjdpunkter. Landskapens formgivning skedde i intimt samband med de orogena rörelsrna. Endast de s. k. »Rumpfstaffeln» måste hänföras till tektoniska vilopauser (*l.c.*). Beroende på höjningsimpulsernas mekanisk-geometriska verkningssätt skiljer förf. på olika morfologiska formresultat (»Verbiegungsrumpftreppen», »Rumpfschollentreppen» o. d.). Bortförandet av lösa produkter (»morphologische Ausräumung») har skett lineärt eller areellt. Det senare fallet har betingats av under lång tid permanenta erosionsbaser med stor regional utbredning. De ha tillkommit antingen omedelbart före orogenesens början (»Initialrümpfe») eller efter orogenesens avslutning (»Sequenzrümpfe»).

Naturligtvis behandlas även många andra hithörande ämnen. Bara några exempel: Trans- och regressionens inflytanden på den morfologiska utvecklingen; den preglaciala dalreliefen och glacialerosionens betydelse, andra klimatförändringars bidrag till morfogenesen, de eoliska inverkningarna o. s. v. I avsnittet över tektoniska inverkningar på dal- och flodsystemens orienteringar sättas dessa i förbindelse med yngre störningar, kollkrökningar, uppvälvningar o. s. v. Det nämnes dock ingenting om det för Alpernas kristallina områden så karakteristiska sambandet mellan orienteringen av petrotektoniska strukturer (främst stängligheter och deras lagbundna spricksystem) och dalarnas och flodernas förlopp (»Gefügerelief»).

Bokens text kompletteras med talrika stratigrafiska tabeller, geologiska kartor och profiler, morfologiska kartor, samt fotografier. En extra eloge skall ges för de vackra och instruktiva landskapsrekonstruktionerna i olika utvecklingsstadier, åskådliggjorda i blockdiagram. De som planscher bifogade, synnerligen innehållsrika översiktskartorna av geologisk-tektonisk och morfologisk natur skulle vunnit mycket i läsbarhet, om de kunde ha tryckts i färg. Detta reducerar dock icke på något sätt det enastående värdet av detta arbete, som lång tid framåt kommer att förbli ett standardverk för geologer och morfologer med intresse för orogenesforskning och bergskedjeområdenas morfogenes, speciellt naturligtvis för dem som arbetar med regional anknytning.

Hans J. Koark

Bestämningsschema för eruptivbergarter

Från Lunds universitets geologisk-mineralogiska institution har utgivits en översikt av eruptivbergarterna efter Tröger i schemaform (40 × 60 cm), avsedd att sättas upp på väggen. Schemat är lättläst och ändå utförligt. Det kostar 2 kr och kan rekvireras från den utgivande institutionen.

Ett häfte om 12 sidor med korta och koncisa bestämningstabeller finns också till ett pris av 1 kr. Publikationerna har i första hand kommit till för att tjäna undervisningsändamål, men eftersom Trögers klassiska bok sedan länge varit utgången ur bokhandeln och några rykten om ny upplaga icke försports, har de värde även för den redan färdigutbildade geologen, när denne önskar friska upp sitt minne på en eller annan punkt.

Per H. Lundegårdh

Hugo Freund: Handbuch der Mikroskopie in der Technik. Band I. Die optischen Grundlagen, die Instrumente und Nebenapparate für die Mikroskopie in der Technik. Teil I. Allgemeines Instrumentarium der Durchlichtmikroskopie. Umschau Verlag. Frankfurt am Main 1957. 681 + 53 sidor, 285 illustrationer, 5 färgplanscher och 18 tabeller. Pris DM 94: —.

Trots att föreliggande volym till numreringen ståtar först i raden i denna mastodontserie om mikroskopet i teknikens tjänst, har den ologiskt nog inte tilldelats samma prioritet när det gäller utgivningsdatum. Detta har dock haft det goda med sig, att det beretts plats även för de allra modernaste instrumenten, som utvecklats under de senaste årens livliga aktivitet. Genom denna försening har redaktören dessutom kunnat tillägna verket minnet av den häromåret avlidne Ernst Leitz (andra generationen) och därmed osökt bringat en hyllning till det företag, som betytt så mycket i detta sammanhang.

Den nära anknytningen till Leitz framträder tydligt redan i inledningskapitlet, vars författare är direkt knuten till företaget. Naturligt nog kommer därmed också mest Leitz' egna produkter i rampljuset i denna mer allmänna översikt av tillgänglig utrustning för mikroskopering i genomfallande ljus. Ett intresseväckande inslag i framställningen är bl. a. den utförliga redovisningen av olika konstruktionstekniska finesser, som man annars sällan ägnar en tanke åt. I det rikhaltiga urvalet av mikroskoptillbehör finns säkert någon nyhet av värde för läsaren. Således var det helt okänt för re att det fanns speciella Brillenträgerokular till gagn för den glasögonprydde. Däremot saknas fortfarande den sedan länge efterlysta okularkonstruktionen med gummilist som stötfångare för sömndruckna huvuden. På köpet får man praktiska vinkar och råd, av vilka de som gäller instrumentvården aldrig kan upprepas för ofta (dammet = mikroskopets fiende nummer ett!).

Elektronmikroskopet har överhuvudtaget ej upptagits till behandling, vilket förefaller vara en välmotiverad gränsdragning, medan polarisations-, faskontrast- och fluorescensmikroskopen vart och ett i kraft av sin speciella karaktär tilldelats ett av de tr efterföljande kapitlen. Den digraste avdelningen i boken omfattar just polarisations mikroskopet och metodiken att studera optiskt anisotropt material. En utredning av indikatrixbegreppet eller av polarisationsoptiska undersökningsmetoder kan ju inte variera på så många olika sätt och det mesta är välkänt från andra handböcker, me man imponeras onekligen av de fräscha och instruktiva illustrationerna, som för övrigt präglar hela boken. Formdubbelbrytning och gelernas optik har gjorts till föremål för särskilt utförligt studium. Bortsett från det teoretiska underlaget saknar framställningen direkt anknytning till mineralogiska metoder, som ju redovisas i ett annat band.

Av stort och allmänt värde är den innehållsrika och synnerligen instruktiva redogörelsen för de optiska principer, på vilka faskontrastmetoden är baserad, medan avsnittet om fluorescensmikroskopering helt är avpassat för medicinskt och biologiskt bruk.

De återstående kapitlen saknar väl också i de flesta fall ett mer direkt intresse från geologisk synpunkt (kemi-mikroskop, mikrospektralfotometri, mikromanipulatorer, mikroskopering vid speciella temperaturförhållanden). Däremot har mikroskopiska längd- och ytmätningar och framför allt olika kvantitativa utvärderingsmetoder tilldragit sig allt större uppmärksamhet under de senaste decennierna. Dessa frågor har här behandlats i två närstående kapitel men kunde gott ha tilldelats större utrymme, gärna på bekostnad av goniometrarna, där åtminstone kontaktgoniometern avgjort inte har något att göra i en handbok av detta slag. Symtomatiskt nog ges avslutningsvis en beskrivning av olika typer av mikrotomer, ytterligare accentuerande att boken i första hand vänder sig till en organiskt inriktad publik.

Kompetensen hos de olika författarna kan förvisso ej ifrågasättas; i en del fall borgar redan deras titlar för stora vetenskapliga meriter. Emellertid är det alltid förknippat med svårigheter att samordna ett flertal alster av olika författare till en logisk helhet. Medan exempelvis en författare bemödar sig om att göra en tydlig åtskillnad mellan lupp och mikroskop, så använder en annan samma begrepp betydligt lättsinnigare. Det kan ej heller undvikas att vissa moment tuggas om i olika sammanhang, men direkt onödig förefaller den dubblering av bildmaterial, som förekommer på flera ställen och som även drabbar så triviala saker som en Monla-lampa. Sådana skönhetsfel förringar naturligtvis inte på något sätt arbetets höga kvalitet.

Bengt Lindqvist

E. Raguin: Géologie du Granite. Deuxième édition revue et mise a jour.
Avant-propos par le professeur C. E. Wegmann. — Masson & Cie
Éditeurs, Paris 1957. 2,400 ffr.

Den andra upplagan av Raguin's granitmonografi är till sin uppläggning tämligen ikartad den första, vilken utkom 1946. Textsidantalet har ökats från 200 till 260 och ntalet textfigurer från 46 till 51. Antalet refererade arbeten har mer än fördubblats, rån 126 till 292. Av de nytillkomna arbetena äro 141 tryckta 1946 eller senare. Att Raguin's bok publicerats på franska, liksom första upplagan, gör kanske att många ngelsk- och tyskspråkiga läsare ej komma att stifta bekantskap med verket, vilket är tt beklaga. Ett starkt skäl för språkvalet finnes dock, när man betänker det stora intresset för granitforskningen inom fransk-språkiga länder. Här behöver endast nämnas rad forskare som Cailleux, Lapparent, Perrin, Raguin, Roubault och Termier betytt ör denna gren av petrologien. I viss mån framgår den franska skolans betydelse av itteraturförteckningen till Géologie du Granite: franskspråkigt 49 %, engelskspråkigt 1 %, tyskspråkigt 17 %, varvid det dock måste påpekas att franskspråkig litteratur nedtagits betydligt mera fullständigt än fallet varit för engelsk- och tyskspråkig.

Den nu utkomna upplagan behandlar på ett föredömligt sätt vitt skilda aspekter på ranitproblemet. En viss omdisponering av materialet har ägt rum, resulterande i en nera logisk behandlingsföljd än fallet var för första upplagan. Som helhet betraktad tgör boken en väl avvägd sammanställning av graniternas karakteristika. De inledane kapitlen om mineralinnehåll och mikrostrukturer har utvidgats betydligt, men dock unde diskussionen om mikrostrukturerna ha förts ännu något utförligare, då dessa i ka hög grad som makrostrukturerna äro avgörande för bergarternas tidigare historia. ven kapitlet om pegmatiter och apliter har starkt utökats; tyvärr har dock Rambergs pegmatitundersökningar från Grönland ej hunnit medtagas i den nya upplagan. I samband härmed måste man beklaga att, tydligen av ekonomiska skäl, inga fotografiska illustrationer medtagits, samtliga figurer äro tecknade. När det gäller en så central och omdiskuterad fråga inom geologien som graniternas genesis, så är illustrationsmaterialet av avgörande betydelse för läsaren, både makro- och mikrostrukturellt. — I avslutningskapitlen behandlas på ett utmärkt sätt förhållandet mellan graniter och malmbildning, ett område där Raguin själv bidragit med grundläggande undersökningar.

Géologie du Granite utgör en av de fåtaliga generella granitbeskrivningarna, och Raguin har lyckats att, i ännu högre grad än för första upplagan, redovisa det sakliga underlag som utgör grunden för de olika »skolornas» uppfattning.

P. Ljunggren

W. Kleber: Einführung in die Kristallographie. Zweite, verbesserte und erweiterte Auflage. VEB Verlag Technik. Berlin 1958. 332 s., 316 fig., 44 tab. Pris kr. 29: 40.

Bland de läroböcker i elementär kristallografi, som utgivits under de sista åren, intar professor Klebers bok en särställning genom sin moderna, väl genomtänkta uppläggning och lyckade avvägning av det rikhaltiga materialet. Boken omfattar morfologisk kristallografi med kristallstrukturlära, kristallkemi och kristallfysik, och ger läsaren en klar bild över de viktigaste och mest aktuella problemställningarna inom kristallografin. Framställningen i boken är klar och kortfattad. På vissa ställen är texten dock allt för knapphändig och därigenom svårbegriplig. Detta medför, att boken knappast kan användas vid självständiga studier. Det är också författarens mening, att boken lämpligast bör användas som komplement till föreläsningar och övningar.

Som varje bok saknar ej heller Klebers verk fel och ojämnheter, men dessa är få och i stort oväsentliga. Sett med en lärares ögon hör delen om morfologisk kristallografi till de svagaste i boken. Egentligen gör sig förf. ej skyldig till många direkta fel. Anmärkningarna mot denna del av boken är mera av allmän karaktär och riktar sig huvudsakligen mot vissa tendenser, som kan spåras även i flera andra nya läroböcker i kristallografi.

Genom den snabba ökningen av våra kunskaper om kristallernas inre byggnad har kristallografernas intresse under de sista 30 åren huvudsakligen inriktats på kristallstrukturen. Morfologisk (fenomenologisk) kristallografi har fått träda i bakgrunden och betraktas numera av somliga forskare med ett visst förakt. Mineralogerna har dock aldrig ifrågasatt kristallmorfologins stora betydelse. Under sista decenniet, i samband med intensiva undersökningar över kristallernas tillväxt och tillväxtformer, har emellertid intresset för morfologin återupplivats. Därför är det ledsamt, att den sobra, noga utarbetade systematiken över de enkla kristallformerna, som kostat flera kristallografgenerationer så mycken möda, övergivits av Kleber. Anm. tycker, att en ofullständig uppräkning av de i olika kristallklasser förekommande formerna, sådan den ges i Klebers bok (men även i andra liknande läroböcker), är, pedagogiskt sett, nästan värdelös. Vad är det för mening med att t. ex. försöka morfologiskt skilja på höger och vänste β-kvartskristaller (fig. 79 på s. 63) när vid beskrivning av klassen 32 inte ges någo upplysning om existensen av vänster och höger kristallformer (trapetsoedrar, trigonal dipyramider, ditrigonala och trigonala prismer!). Nybörjaren i kristallografi komme vid granskning av de två kvartskristallerna i fig. 79 att undra, enligt vilka regler ma bestämmer vänster och höger former. Vilken av dessa kristaller kallas för höger? Oc varför? Samma gäller fig. 57, 123 och i synnerhet 113, då i texten inte har omnämnts att kristallerna på denna ritning befinner sig i icke kommensurabla lägen (vänstra kristallbilden är vriden 90° i förhållandet till den högra). Ordföljden »höger» och »vänster» i texten till dessa bilder är missvisande (utom fig. 79), då den inte står i relatio till vänster- och högerkristallens position i ritningen. Det skulle väl inte vara så svår att på några sidor upprätta tabellarisk sammanställning över samtliga enkla kristallformer och deras symboler. En sådan sammanställning är lika eller t. o. m. mera berättigad än den 7-sidiga tabellen över rymdgruppssymboler på s. 83—89. Men framförallt måste det ordentligt förklaras, hur man kommer till de omnämnda enkla formerna och deras formsymboler.

Man skulle också velat se skarpare definitioner på vissa fundamentala begrepp, t. ex. kristallografiska axlar och enhetsparametrar, då skillnaden mellan dessa i boken aldrig riktig kommer fram. Varför använder inte förf. de för kristallografiska axlar av »*International Tables for X-Ray Crystallography*» rekommenderade symbolerna *x*-, *y*-, *z*-?

Några figurer är missvisande. På bilden, som skall illustrera den sextaliga inversionsaxelns verkningssätt, är symmetriplanet onödigt inritat (fig. 49). Detta stereogram skall antingen uppvisa $\bar{6}$ (enbart!) eller 3 + m. Samma fel har gjorts på stereogrammet för $\bar{6}$ på s. 52. Kanske bör det omnämnas, att man påträffar detta misstag även på s. 27 i »*International Tables for X-Ray Crystallography*». Samtliga i fig. 50 avbildade stereogram är felaktigt försedda med ett symmetriplan. I stereogrammet för m 3 på s. 52 saknas tre tvåtaliga axlar.

Med hänsyn till de i litteraturförteckningen bl. a. rekommenderade ryska läroböckerna skulle det varit lämpligt att i anslutning till beskrivningen av rymdgrupperna omnämna antisymmetriprincipen och Schubnikovs grupper.

Förf. deklarerar i inledningen, att han i den nya upplagan infört den terminologi för ljusbrytningsindices, som används bl. a. i Trögers tabeller. Denna mycket olyckliga terminologi (jfr GFF 75, 1953, s. 523—524) har väckt stark opposition, särskilt i USA. Benämningarna X, Y, Z för indikatrisens axlar härstammar från Iddings (1911). Symbolerna n_x,n_y,n_z för ljusbrytningsindices infördes för flera år sedan av H. Winchell. Huvudsyftet med Iddings beteckningar var, att man i kristalloptiska beskrivningar och ritningar skulle kunna skilja mellan svängningsriktningar och ljusbrytningsindices för motsvarande vågnormaler. Med X, Y, Z betecknas sålunda den 3-axliga optiska indikatrisens läge i kristallen och med n_x,n_y,n_z ljusbrytningsindices. Övergången till den nya symboliken har inte medfört någon större fördel för Klebers bok. Tvärtom, framställningen har därigenom förlorat i klarhet. I motsats till Winchell och Tröger använder Kleber på samtliga ritningar n_x,n_y,n_z och icke X, Y, Z för att beteckna indikatrisens läge i kristallen. Men på ett ställe i texten (s. 247—248) använder han för samma ändamål XYZ.

Anm. kunde i boken inte hitta någon figur, som visar en typisk axelbild för sneda snitt i tvåaxliga kristaller. Fig. 281 ger ingen riktig uppfattning om de typiska dragen hos sneda snitt, eftersom alla tre rader axelbilder demonstrerar specialfall (snittet vinkelrätt mot optiska axelplanet). Denna ritning härstammar egentligen från Levy och Lacroix och är endast omritad av Chudoba.

Trots alla dessa anmärkningar måste professor Klebers bok i sin helhet anses mycket lyckad och kan på det varmaste rekommenderas åt alla, som önskar bilda sig en uppfattning om den moderna kristallografin med dess problem och arbetsinriktningar. Det råder inget tvivel om, att denna utmärkta lärobok kommer att bli mycket uppskattad av studerande vid våra universitet och högskolor. Det i förhållande till den påkostade utstyrseln relativt låga priset kommer väsentligt att bidra till bokens spridning.

Otto Mellis

Mötet den 6 november 1958

Närvarande 35 personer.

Ordföranden, hr T. Eriksson, förklarade sammanträdet öppnat och meddelade följande:

Styrelsen har enhälligt utsett professor A. A. Bogdanov, Moskva, till korresponderande ledamot av Föreningen. Bogdanov, som är professor i geologi och tektonik, har särskilt sysslat med utgivandet av geologiska och tektoniska kartor. Han är en av initiativtagarna till den stora tektoniska kartan över U. S. S. R. av år 1957. I sin verksamhet har Bogdanov visat livligt intresse för Skandinaviens geologiska förhållanden.

Styrelsen har till ledamöter av Föreningen invalt amanuens Roland Skoglund, Uppsala, föreslagen av hr Thorslund, och fil. stud. Een Pärnamaa, Lund, föreslagen av hrr P. Ljunggren och J. von Feilitzen samt fil. stud. Lars E. Kers, Göteborg, föreslagen av hrr K. Nilsson och G. Ekström.

Därefter överlämnades ordet till professor A. C. Blanc från Istituto Italiano di Paleontologia Umana i Rom, som höll ett med talrika färgbilder illustrerat föredrag med titeln: The Pleistocene sequences of Rome and of the littoral paleolithic sites of the Tyrrhenian coast of Italy.

Med anledning av föredraget yttrade sig hrr G. Hoppe och C. G. Wenner.

Vid mötet utdelades nr 494 av Förhandlingarna.

Mötet den 4 december

Närvarande 72 personer.

Ordföranden, hr T. Eriksson, öppnade mötet och meddelade, att styrelsen till ledamöter i Föreningen invalt civilingenjör Kirsten Heien-Larssen, Stockholm, föreslagen av hrr T. Eriksson och B. Järnefors, civilingenjör Rune Lundström, Stockholm, föreslagen av hrr K. E. Mars och T. Eriksson, överdirektör K. A. Lindbergson, Stockholm, föreslagen av hr G. Lundquist och slutligen fil. mag. Ebbe Zachrisson, Stockholm, föreslagen av hr Gavelin.

Förrättades val av styrelse och revisorer för år 1959, varvid utsågos:

till ordförande hr O. Meier
till sekreterare hr E. Åhman
till redaktör för Förhandlingarna hr P. H. Lundegårdh
till skattmästare hr O. Gabrielsson
till övriga ledamöter av styrelsen hrr T. Eriksson och E. Fromm.

Till revisorer att granska 1958 års förvaltning utsågos hrr B. Dahlman och B. Järnefors med hr J. Lundqvist som suppleant.

Herr R. Frietsch höll därefter ett med kartor och talrika färgbilder illustrerat föredrag om: Nya synpunkter på Kirunatraktens stratigrafi.

Med anledning av föredraget yttrade sig hrr Edelman, Geijer, Hagerman, Henriksen, Lindroth, Looström, Sundius och föredragshållaren. Referat av diskussionsinläggen införas i häfte 1, 1959.

Geolognytt

Författare till mineralogiska uppsatser uppmanas att omgående översända separat av dessa till professor Sven Hjelmqvist, Geol.-miner. inst., Lund, som kommer att referera dem i *Mineral Abstracts*.

Bergsingenjör W. Sidenvall, Uppsala, har från 1 jan. 1959 utnämnts till gruvingenjör vid Bergsstaten med placering i Västra bergmästaredistriktet, Nora.

Vetenskapsakademien har utdelat sin äldre Linnémedalj i guld till professor Astrid Cleve, Uppsala, för hennes betydande insats på diatomacéforskningens fält.

Björkénska priset har av större akademiska konsistoriet vid Uppsala universitet tilldelats professor Erik Norin, Uppsala, för hans under åren 1951—58 utgivna arbeten rörande undersökningar av sedimentproppar från Tyrrhenska sjön.

Professor G. Erdtman, Stockholm, har av universitetet i Córdoba, Argentina, inbjudits att hålla en kurs i palynologi i december 1958.

Henrik Munthes minnesfond

Förre undervisningsrådet Harald Wallin, Stockholm, har i dagspressen tagit initiativ till en insamling för att hedra och bevara minnet av framlidne professorn Henrik Munthe. Henrik Munthe var föregångsman inom den kvartärgeologiska forskningen, speciellt märks hans banbrytande insatser för utforskandet av Östersjöns geologiska utveckling. Vid sidan av sin tjänst som statsgeolog och sin forskning ägnade Munthe sig synnerligen aktivt åt skyddet och vården av Gotlands natur och kulturförhållanden. De som önskar mer varaktigt befästa och hedra Henrik Munthes minne och gärning vill vi uppmana att på sätt som undervisningsrådet Wallin föreslagit göra detta genom att insända ett bidrag till »Henrik Munthes minnesfond för Gotlands natur» under adress Svenska Naturskyddsföreningen, Riddargatan 9, Stockholm Ö, Postgiro 2166.

Stockholm och Visby den 21 oktober 1958

Åke Hovgard
Landshövding

Gösta Lundqvist
Professor, statsgeolog

Gösta Wallin
Justitieråd, ordförande i
Svenska Naturskyddsföreningen

Direktorn för Geologiska forskningsanstalten i Finland prof. Aarne Laitakari har i anledning av uppnådd pensionsålder beviljats avsked från den 1 januari 1959. Han har förestått nämnda anstalt sedan år 1935.

Samordning av åldersbestämningar i Sverige

Vid ett möte i Stockholm den 12.11.1958 mellan representanter för Geologiska Undersökningen, Stockholms Högskola och AB Atomenergi dryftades de olika möjligheter, som den närmaste framtiden finnas att få absoluta åldersbestämningar utförda av svenska bergarter. Då förutom de masspektrometriska blybestämningar, som utföras av AB Atomenergi, endast begränsade möjligheter finnas att utomlands få kompletterande mätningar utförda enligt andra metoder beslöts att, för undvikande av onödiga dubbelmätningar, rekommendera en samordning av forskningsprogrammet. Denna kan enligt mötet tillsvidare ske genom att centralisera registreringen av proven med angivande av noggrann fyndortsbeskrivning, bergart, mätmetod, beräknad ålder samt vem som utfört mätningen. För denna uppgift utsågs fil. lic. E. Welin, AB Atomenergi, till vilken förfrågningar om utförda bestämningar etc. kan ställas samt uppgifter om planerade mätningar insändas.

Eric Welin

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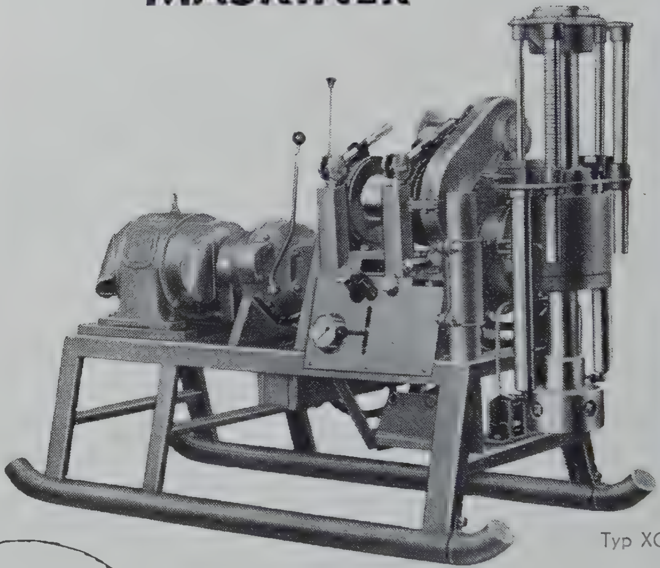

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SAHAMA, TH. G., 1954: Mineralogy of mafurite. Bull. Comm. géol. Finl., N:o 166

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Geologiska Föreningens sekreterare, Fil. Lic. Erik Åhman och redaktör, Docent P. H. Lundegårdh, träffas i Föreningens angelägenheter å Sveriges Geologiska Undersökning, tel. 34 97 90, säkrast tisdagar och torsdagar kl. 13—14.

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Personlig kallelse till sammanträdena utfärdas till ledamöter, som så önska.

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